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ELECTRONICS DATA HANDBOOK

By William Barden

Electronics Data Reference Book

by

William Barden, Jr.

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Section 1.
Electronics Formulas and Laws

Ohm's Law.

Ohm's Law relates the current, voltage, and resistance in an electrical circuit. According to Ohm's Law, the current in the circuit of Figure 1-1 is directly proportional to the applied voltage and inversely proportional to the resistance of the circuit. If I stands for current in amperes, E stands for electromotive force, or voltage, in volts, and R stands for resistance in ohms, then

$$I = \frac{E}{R} \qquad E = I \times R \qquad R = \frac{E}{I}$$

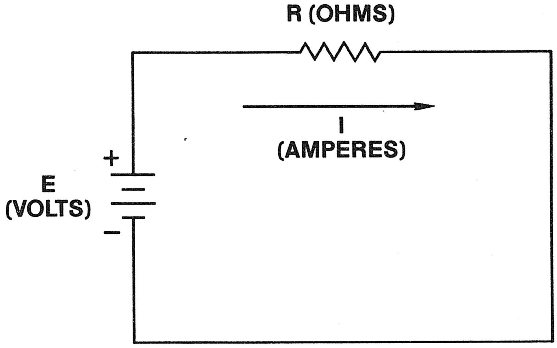


Figure 1-1. Ohm's Law Circuit

Example: If R = 1000 ohms and E = 10 volts, then the current will equal

$$I = \frac{10}{1000} = 1/100 \text{ ampere} = 10 \text{ milliamperes}$$

DC Power

Electrical power is equal to voltage times current. Power is the rate of doing work and is expressed in electrical circuits by the watt. Power, current, and voltage can be related by dc power equations. In the following, power is in watts, current is in amperes, and resistance is in ohms:

$$P = E \times I \qquad P = \frac{E^2}{R} \qquad P = I^2 \times R$$

Example: If R = 1000 ohms and E = 10 volts, then the power used in the circuit is

$$P = \frac{E^2}{1000} = \frac{100}{1000} = 1/10 \text{ watt} = 100 \text{ milliwatts}$$

Ohm's Law and Power Nomograph

Figure 1-2 shows a nomograph that can be used to calculate current, voltage, resistance, or power, given two of the four variables. To use the nomograph, find the first value on one scale, the second on another scale, and lay a straight-edge from one point to the other. The remaining two values are read from the other two scales. Two sets of scales are superimposed on the four axes of the nomograph. When using the nomograph, always work with either the left or right scales on all four axes.

Example: Given a resistance of 1000 ohms and a voltage of 10 volts, what is the current and power dissipation? The resistance is found on the Resistance scale and the voltage is found on the Voltage scale. When the two points are connected by a straight-edge, the power is found to be 0.1 watt and the current to be 10 milliamperes.

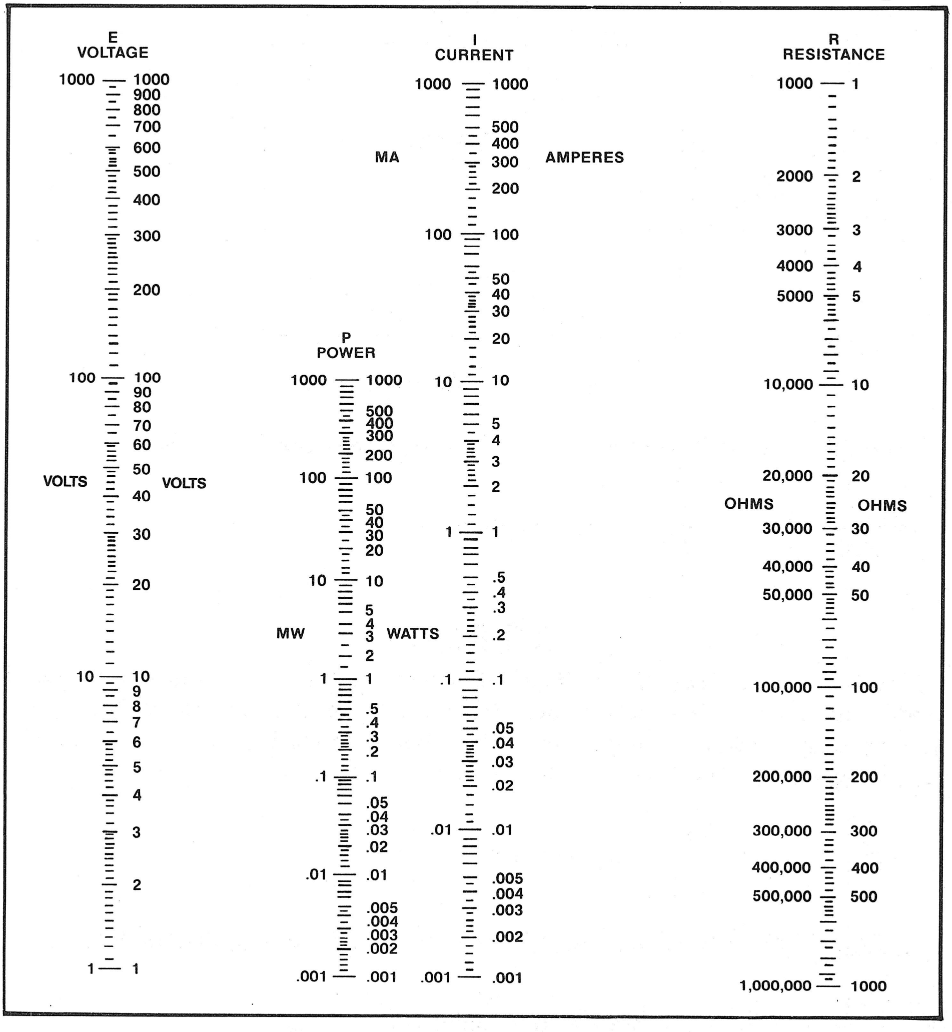


Figure 1-2. Ohm's Law Nomograph

Calculating Total Resistance

Resistances in Series.

When more than one resistor is used in series in an electrical circuit, the total resistance is found by summing the individual resistances. If the resistances are called R_1, R_2, R_3, etc., as shown in Figure 1-3, then the total resistance is

$$R_{TOTAL} = R_1 + R_2 + R_3 + \ldots$$

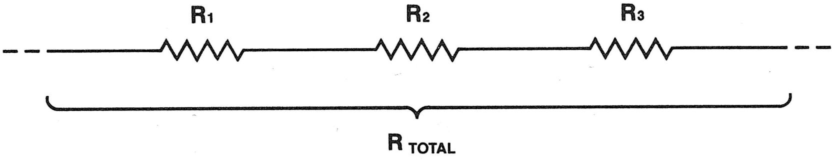


Figure 1-3. Resistance in Series

Resistances in Parallel

When more than one resistor is used in parallel in an electrical circuit, as shown in Figure 1-4, then the total resistance is found by

$$R_{TOTAL} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots}$$

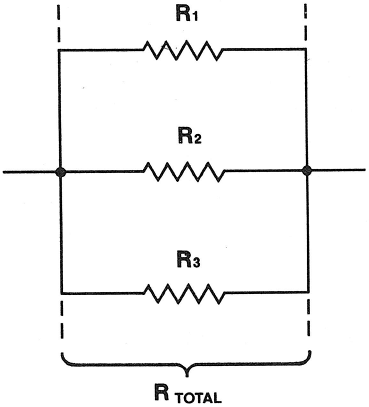


Figure 1-4. Resistance in Parallel

When only two resistors are used in parallel, this formula may be used

$$R_{TOTAL} = \frac{R_1 \times R_2}{R_1 + R_2}$$

When two resistances are used in parallel, the nomograph shown in Figure 1-5 may also be used to quickly calculate total resistance. To use the nomograph, find the first resistance value (R_1) on the left-hand R1 axis and the second resistance value (R_2) on the right-hand axis. Connect these points by a straight-edge. The intersection on the R_{TOTAL} axis is the total resistance. Ignore zeroes when using smaller resistances or add zeroes when using larger resistances. The example shown also holds true for resistors of 15 and 8 ohms (result is 5.2) and 150,000 and 80,000 ohms (result is 52,000 ohms). However, both ranges must be the same (the result is *not* 5,2000 ohms for 15,000 ohms and 80,000 ohms).

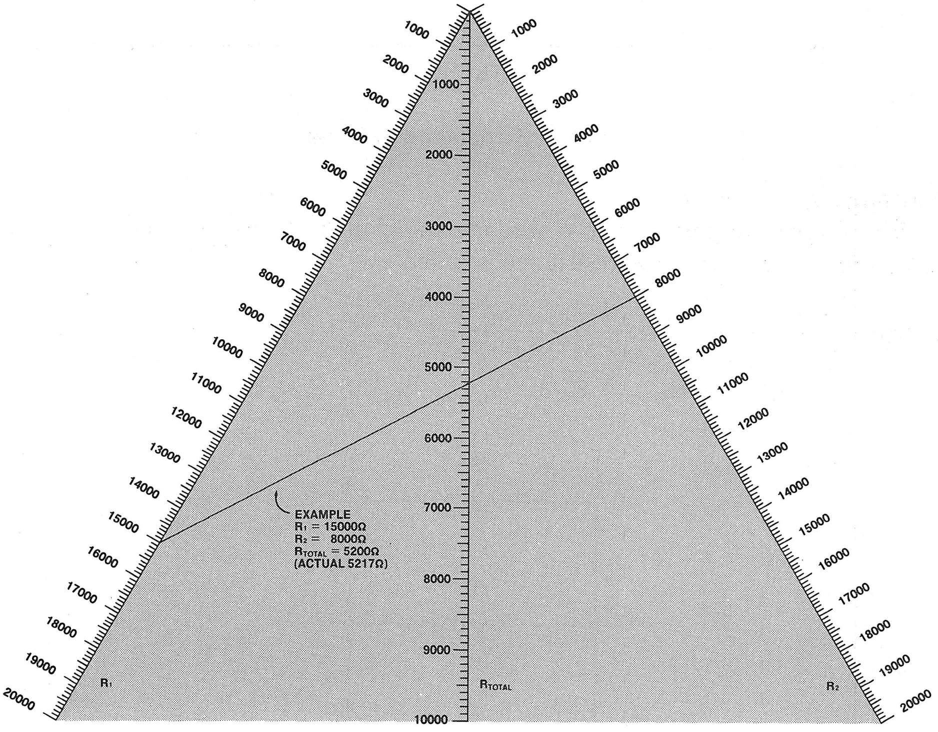


Figure 1-5. Parallel Resistance Nomograph

If the total resistance required is known, find the resistance on the R_{TOTAL} axis and pivot the straight-edge about this point to find resistor combinations that will the required total value.

Resistances in Series-Parallel.

When resistances are in combinations of serial and parallel, as shown in Figure 1-6, calculate the total resistance by breaking the circuit into parts and employing the series and parallel rules.

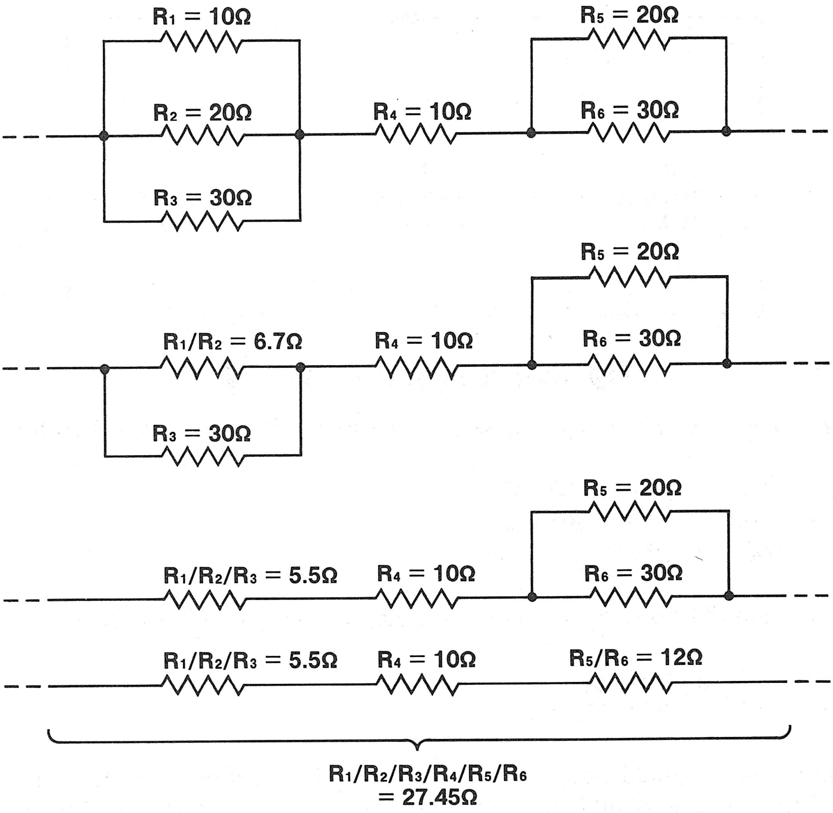


Figure 1-6. Series/Parallel Resistance Example

Example: In the circuit shown, the total resistance of R1 and R2 is 6.7 ohms, from the parallel resistance nomograph. The total resistance of R1/R2/R3 is therefore 5.5 ohms, again from the nomograph. The total resistance of R5 and R6 is 12 ohms from the nomograph, making the grand total resistance 27.5 ohms (5.5 + 10 + 12 ohms)

Kirchhoff's Laws

Kirchhoff's Laws are an expansion of Ohm's Law applied to electrical *networks.* Kirchhoff's First Law states that the applied voltage must be equal to the sum of the voltage drops in a direct current series circuit. Figure 1-7 illustrates this law. In the figure E_{TOTAL} is the applied voltage and E_1, E_2, E_3 are the voltage drops across resistors R_1, R_2, and R_3. Assume the applied voltage is 12 volts. The total current in the circuit is found by calculating the total resistance and applying Ohm's Law:

$R_{TOTAL} = 1000 + 500 + 2100 = 3600$ ohms
$I = 12/3600 = .0033$ amperes = 3.33 milliamperes

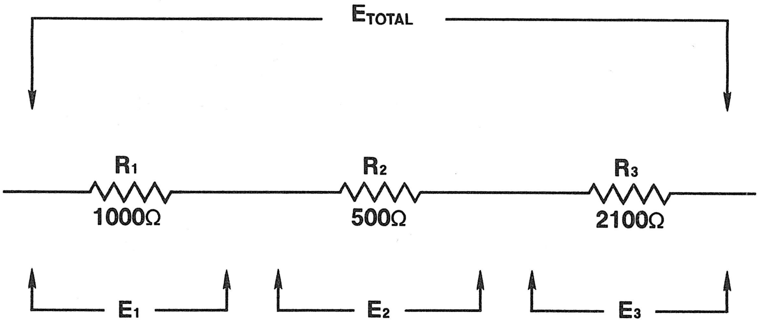


Figure 1-7. Kirchoff's Law—Example 1

By Ohm's Law, the voltages appearing across R_1, R_2, and R_3 are therefore

$E_1 = .00333 \times 1000 = 3.33$ volts
$E_2 = .00333 \times 500 = 1.665$ volts
$E_3 = .00333 \times 2100 = 6.993$ volts

By Kirchhoff's Law, the voltages must add up to the applied voltage

$E_1 + E_2 + E_3 = E_{TOTAL}$
$3.3 + 1.67 + 6.99 = 12.0$ volts

Kirchhoff's Second Law states that the algebraic sum of currents flowing towards a single connection point is zero. In the circuit of Figure 1-8, the sums I_1, I_2, and I_3 must equal I_{TOTAL}, the total current from the applied voltage. Assume the applied voltage is 12 volts. The total resistance of the circuit is

$$R_{TOTAL} = \frac{1}{\frac{1}{1000} + \frac{1}{500} + \frac{1}{2100} +} = 287 \text{ ohms}$$

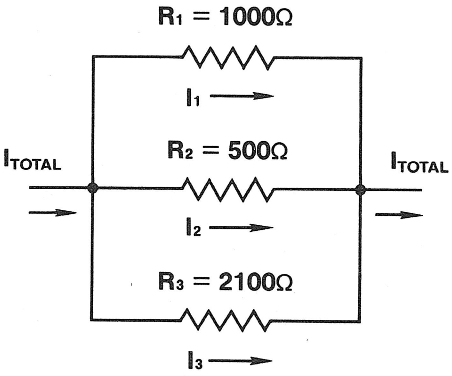


Figure 1-8. Kirchoff's Law—Example 2

By Ohm's Law, the total current through the circuit is

$I_{TOTAL} = 12/287 = .0418$ amperes

The total currents through R_1, R_2, and R_3 are

$I_1 = 12/1000 = .012$ amperes
$I_2 = 12/500 = .024$
$I_3 = 12/2100 = .0057$

By Kirchhoff's Second Law,

$I_{TOTAL} = I_1 + I_2 + I_3$
$.0418 = .012 + .024 + .0057$

DC Meter Formulas

A moving coil or moving vane type of meter measures direct current by electromagnetic deflection of a pointer over a calibrated scale on the face of the meter. Meters of this type generally measure current in the microamp or milliamp range. However, it is possible to add external resistances to the basic meter to increase the current range to be measured and also to provide measurement of voltage and resistance.

Measuring the Internal Resistance of a Meter

Before external resistances can be added, the internal resistance of the meter should be found, if not stated by the manufacturer. Figure 1-9 shows a method for measuring the internal resistance. R_1 is adjusted for a full scale reading on the meter. R_2 is then added to the circuit and adjusted for a half-scale meter reading. R_2 is then removed from the circuit; its resistance is equal to the internal resistance of the meter.

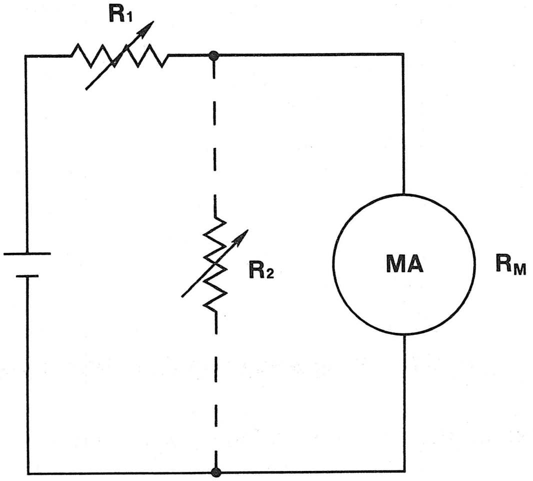


Figure 1-9. Finding the Internal Resistance of a Meter

Extending the Current Range of the Meter

An external resistance can be added in parallel with the meter to extend the current range, as shown in Figure 1-10. When this is done, only a portion of the total current in a cicuit will flow through the meter. The shunt resistance required for a given current multiplication can be found by

$$R = \frac{R_M}{N - 1}$$

where R is the resistance of the shunt, R_M is the internal resistance of the meter, and N is the multiplication factor.

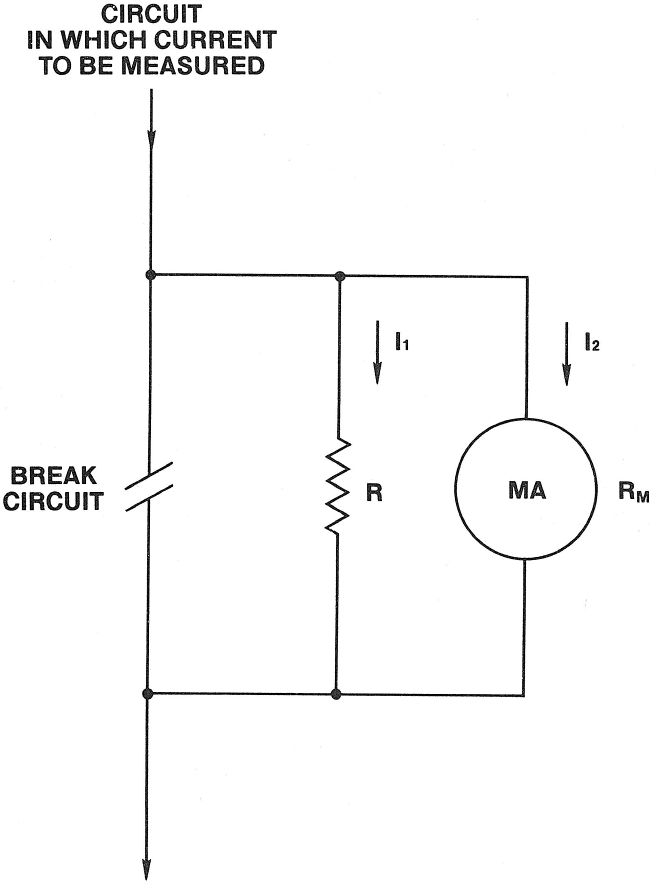


Figure 1-10. Using a Meter in Extended Range

Example: To extend the current by a factor of 10, the shunt resistance must be $R_M/9$.

Using the Meter as a Voltmeter

An external series resistance can be added to the meter to allow voltage measurements, as shown in Figure 1-11. When this is done, the pointer deflection is proportional to the voltage drop across the meter. The higher the internal resistance of the meter, the more accurate will be the meter reading. (I.e. an ideal meter would have infinite internal resistance so as not to load the circuit in which it is being used.) The external resistance required can be calculated from Ohm's Law.

Example: Find the external resistance for a meter that requires 100 microamperes for full scale deflection of the needle and which is to be used for a 0 to 10 volt voltmeter.

$$R = \frac{10 \text{ volts}}{100 \times 10^{-6}} - R_M = 100{,}000 \text{ohms} - R_M$$

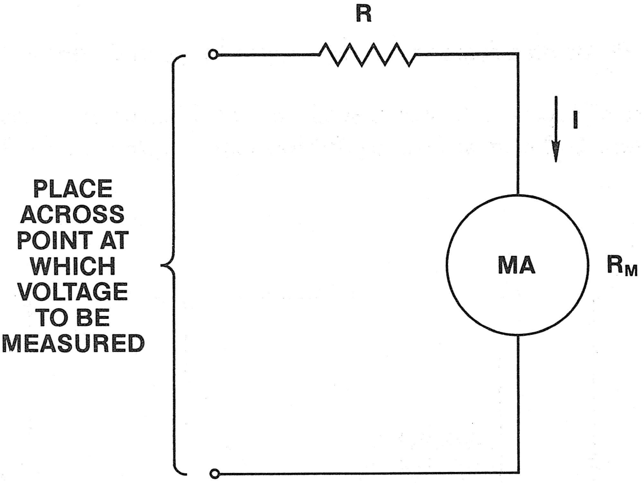


Figure 1-11. Using a Meter as a Voltmeter

Using the Meter as an Ohmmeter

To use the meter in measuring resistance, a small battery is used, as shown in Figure 1-12. A variable resistance is adjusted to provide full-scale deflection of the needle when terminals 1 and 2 are shorted. Adding an unknown resistance will then cause a partial deflection of the needle according to this formula:

$$R = (R_1 + R_M)\frac{I_1 - I_2}{I_2}$$

where I_1 is the current reading with the terminals shorted, I_2 is the current reading with the resistance to be measured, R_1 is the adjustable resistance value for full-scale reading for a short, R_M is the internal resistance of the meter, and R is the value of the external resistance.

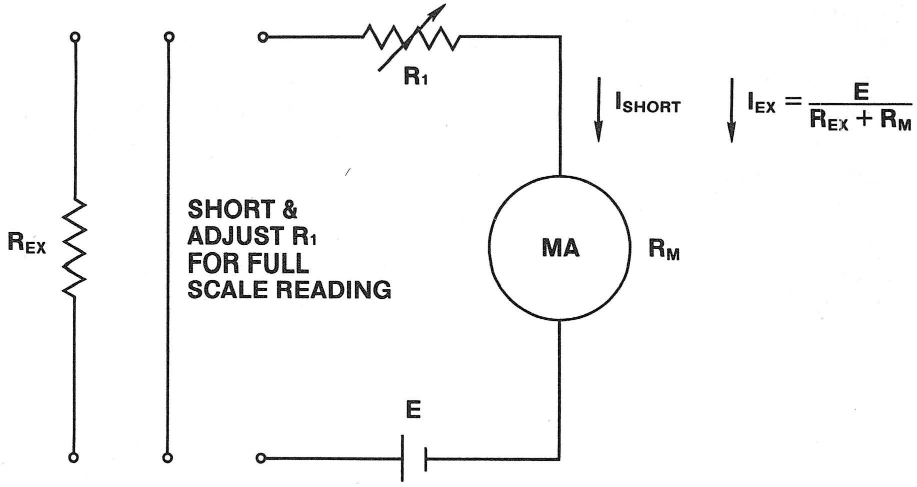


Figure 1-12. Using a Meter as an Ohmmeter for High External Resistances

The circuit of Figure 1-12 works well only on high external resistances. The circuit of Figure 1-13 is an alternative for low external resistances. The formula is

$$R = R_M \frac{I_2}{I_1 - I_2}$$

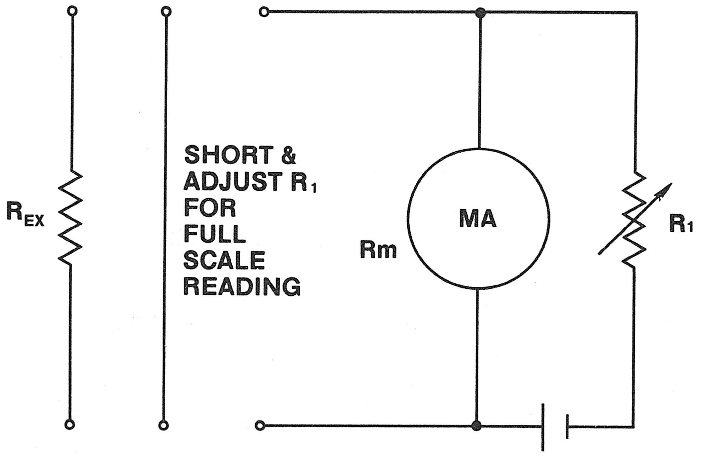


Figure 1-13. Using a Meter as an Ohmmeter for Low External Resistances

Capacitance

A *capacitor* has the ability to store electricity in an electric field between the plates of the capacitor. The symbol for a capacitor represents the plates schematically by two parallel lines representing the plates. The capacity for storing an electrical charge is given by the formula

$$C\ (\text{farads}) = 0.224\frac{KA}{d}(N - 1)$$

where K is the dielectric constant of the material between the plates (see section 6), A is the area of one side of one plate in inches, d is the separation of the plates in inches, N is the number of plates, and C is the capacitance in farads. Convenient units are microfarads (1/1,000,000th farad, or $1/10^6$) and micromicrofarads (picofarads) ($1/10^{12}$).

Direct current cannot flow through a capacitor, but an alternating current applied to a capacitor will result in current flow as the capacitor attempts to charge and discharge.

Calculating Total Capacitance

Capacitors in Parallel

When more than one capacitor is used in parallel in an electrical circuit, the total capacitance is found by summing the individual capacitances. If the capacitors are called C_1, C_2, C_3, etc., as shown in Figure 1-14, then the total capacitance is

$$C_{TOTAL} = C_1 + C_2 + C_3 + \ldots$$

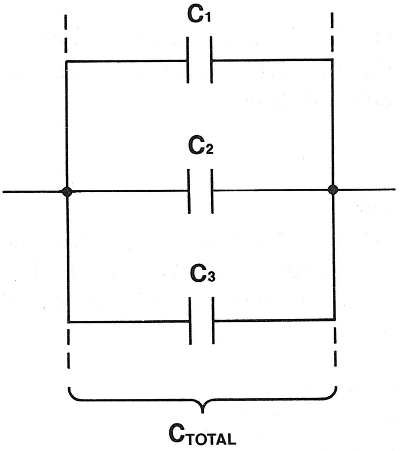


Figure 1-14. Capacitances in Parallel

Capacitances in Series

When more than one capacitor is used in series in an electrical circuit, as shown in Figure 1-15, then the total capacitance is found by

$$C_{TOTAL} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots}$$

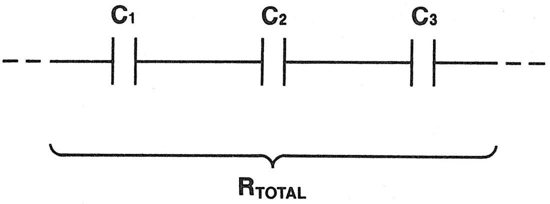


Figure 1-15. Capacitances in Series

When only two capacitors are used in series, this formula may be used

$$C_{TOTAL} = \frac{C_1 \times C_2}{C_1 + C_2}$$

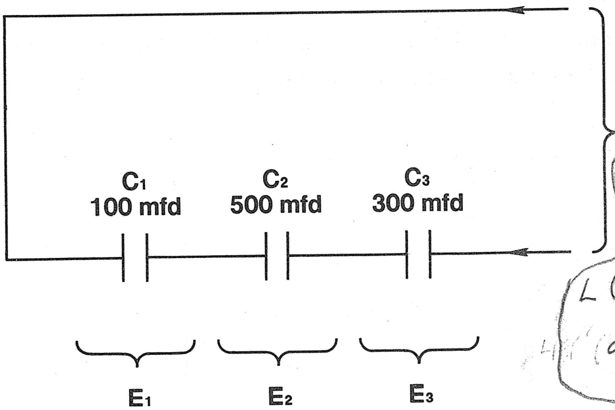
When two capacitors are used in serial, the nomograph shown in Figure 1-5 may also be used to quickly calculate total capacitance. To use the nomograph, find the first capacitance value on the left-hand R_1 axis and the second capacitance value on the right-hand R_2 axis. Connect these points by a straight-edge. The intersection on the R_{TOTAL} axis is the total capacitance. Ignore zeroes when using smaller capacitances or add zeroes when using larger capacitances. The example shown for the resistance example would apply for capacitances of 1500 picofarad and 800 picofarad (result of 520 picofarad).

If the total capacitance required is known, find the capacitance on the R_{TOTAL} axis and pivot the straight-edge about this point to find capacitor combinations that will provide the required total value.

Voltage across Capacitors

The voltage across capacitors connected in series is proportional to the total capacitance divided by the individual capacitance value. In the circuit of Figure 1-16, for example, the total capacitance is 65.4 microfarads. The voltages appearing across C_1, C_2, and C_3 are

$E_1 = (65.4/100) \times 12 = 7.8$ volts
$E_2 = (65.4/500) \times 12 = 1.6$ volts
$E_3 = (65.4/300) \times 12 = 2.6$ volts



for a fixed length of wire:

$$L\,(\mu H) = \frac{L^2}{4\pi^2(9R+10L)}$$ wire length in inches

$$9R+10L = \frac{L^2}{L\,(\mu H)\,4\pi^2}$$

Figure 1-16. Voltage Across Capacitors—Example

Inductance

An *inductor* has the ability to store electricity in a magnetic field surrounding a conductor. This effect is intensified when the conductor is formed into a coil. The symbol for an inductor represents the coil schematically. The capacity for storing electrical energy in the magnetic field of an inductor is approximately given by the formula

$$L\text{ (microhenries)} = \frac{\overset{1.475}{R^2N^2}}{9R + 10L}$$

$$\sqrt{\frac{L(\mu H)(9R+10L)}{R^2 \cdot 1.475}} = N$$

where R is the radius of the coil in inches, L is the length of the coil in inches, N is the number of turns over the length of the coil, and L is the inductance in µhenries (1/1,000,000 henry).

Calculating Total Inductance

Inductors in Series

When more than one inductor is used in series in an electrical circuit, the total inductance is found by summing the individual inductances, providing that the magnetic fields of the inductors do not interact. If the inductors are called L_1, L_2, L_3, etc., as shown in Figure 1-17, then the total inductance is

$$L_{TOTAL} = L_1 + L_2 + L_3 + \ldots$$

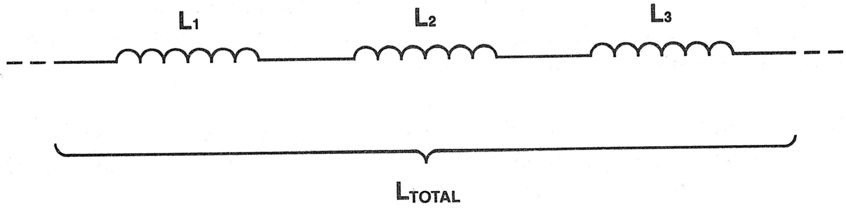


Figure 1-17. Inductances in Series

Inductors in Parallel

When more than one inductor is used in parallel in an electrical circuit, as shown in Figure 1-18, then the total inductance is found by

$$L_{TOTAL} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots}$$

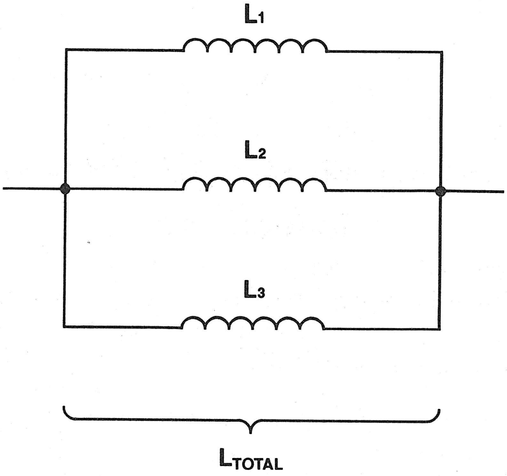


Figure 1-18. Inductances in Parallel

providing that the magnetic fields of the inductors do not interact.

When only two inductors are used in parallel, this formula may be used

$$L_{TOTAL} = \frac{L_1 \times L_2}{L_1 + L_2}$$

When two inductors are used in parallel, the nomograph shown in Figure 1-5 may also be used to quickly calculate total inductance. To use the nomograph, find the first inductance value on the left-hand R_1 axis and the second inductance value on the right-hand R_2 axis. Connect these points by a straight-edge. The intersection on the R_{TOTAL} axis is the total inductance. Ignore zeroes when using smaller inductances or add zeroes when using larger inductances. The example shown for the resistance example would apply for inductances of 1500 microhenries and 800 microhenries (result of 520 microhenries).

If the total inductance required is known, find the inductance on the R_{TOTAL} axis and pivot the straight-edge about this point to find inductor combinations that will provide the required total value.

Reactance

Alternating currents containing capacitances and inductances experience opposition to their flow analogous to the opposition of resistance in direct current circuits. This opposition is called reactance and is measured in ohms. The reactance of a capacitor can be computed by

$$X_C = \frac{1}{2\pi fC} \qquad f = \frac{1}{2\pi C X_c} \qquad C = \frac{1}{2\pi X_c f}$$

where X_C is the reactance in ohms, f is the frequency in hertz, C is the capacitance in farads, and π is 3.14159.

The reactance of an inductor can be computed by

$$X_L = 2\pi fL \qquad f = \frac{X_L}{2\pi L} \qquad L = \frac{X_L}{2\pi f}$$

where X_L is the reactance in ohms, f is the frequency in hertz, L is the inductance in henries, and π is 3.14159.

Reactances in Series and Parallel

For reactances of the same kind (capacitive or inductive), the total reactance can be found by the same formulas used to compute series or parallel resistances (see "Calculating Total Resistance").

Ohm's Law for Reactance

Current in a circuit containing only capacitors leads the applied ac voltage by 90 degrees. Current in a circuit containing only inductors lags the applied ac voltage by 90 degrees. Current in a circuit containing only capacitive or inductive reactance (but not both) can be found by Ohm's Law for Reactance:

$$I = \frac{E}{X} \qquad E = I \times X \qquad X = \frac{E}{I}$$

where E is the electromotive force in volts, I is the current in amperes, and X is inductive or capacitive reactance.

Example: If E = 10 volts at 400 hertz, then the capacitive reactance of a 10 microfarad capacitor will be

$$X_C = \frac{1}{2\pi \times 400 \times 10 \times 10^{-6}} = 39.8 \text{ ohms}$$

and the current through the capacitor will be:

$$I = \frac{10}{39.8} = 0.25 \text{ amperes}$$

Reactance Charts

Figure 1-19 is a reactance nomograph that allows you to calculate inductive and capacitive reactances at frequencies from 100 hertz to 100 Megahertz. To find reactance, locate the capacitance or inductance value on one of the diagonal lines, or estimate the parallel line for an intermediate value. Find the junction of the line and the frequency (or the junction of the line and the reactance) and then read off the corresponding reactance (or frequency) value from the other axis.

Example: Find the capacitive reactance of .002 mfd at 2 Megahertz frequency. The .002 capacitance line is above the parallel to and that distance away from the .0025 mfd, the intersection of the straight-edge and vertical line for 2 Megahertz corresponds to about 42 ohms capacitive reactance.

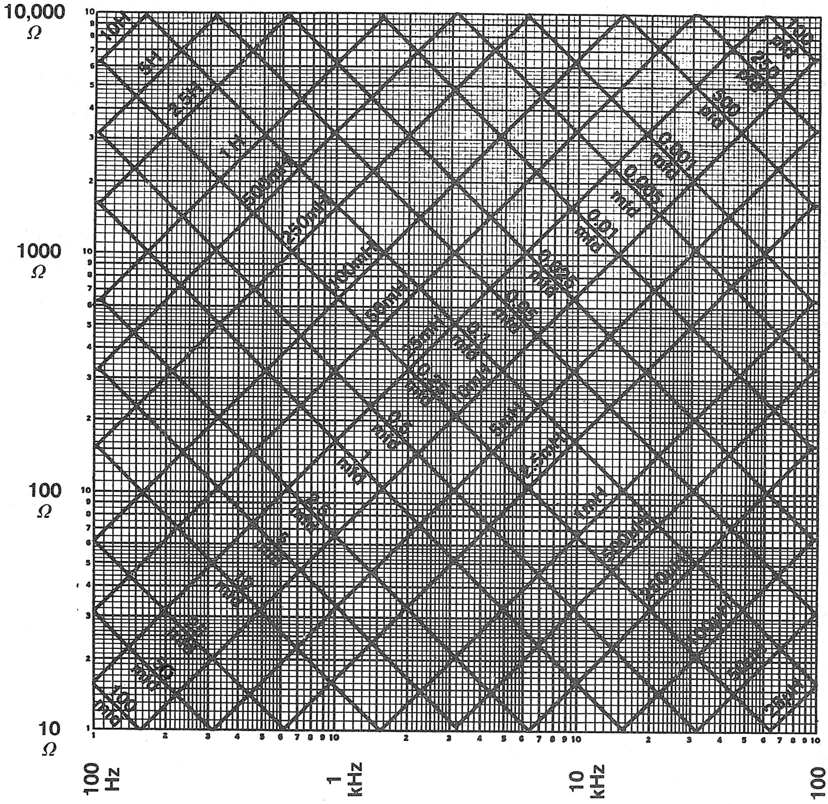


Figure 1-19. Reactance Nomograph

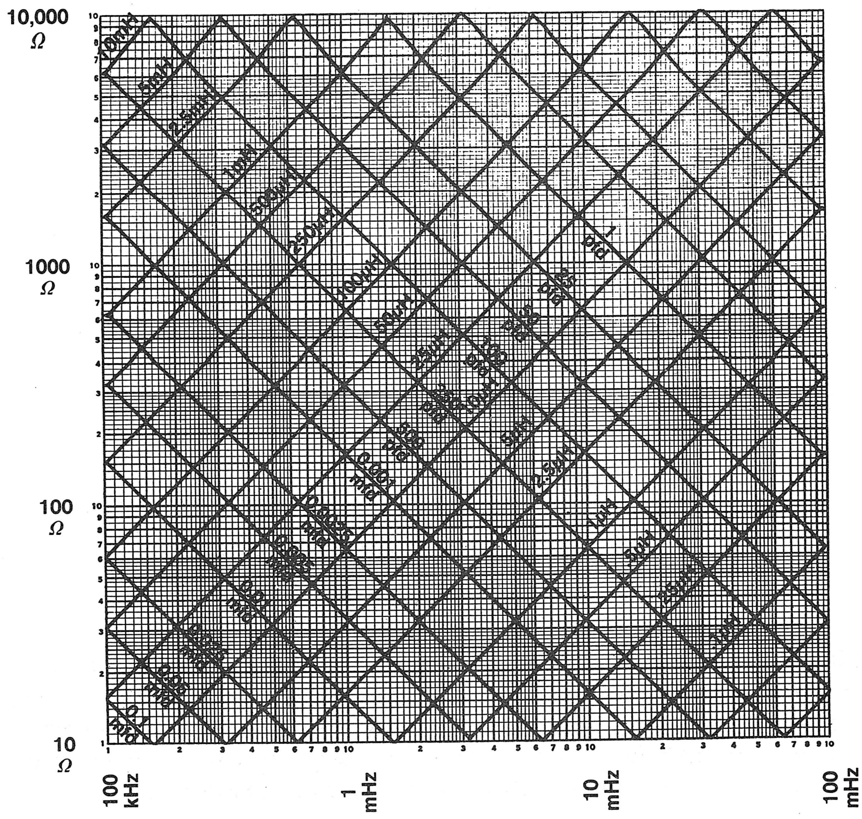


Figure 1-19. Reactance Nomograph (cont.)

Resonance

Capacitive reactance decreases with increasing frequency while inductive reactance increases with increasing frequency. If a circuit contains both an inductor and capacitor (see Figure 1-20), there is a frequency for which capacitive reactance equals inductive reactance. This is called the resonant frequency and can be found by

$$f = \frac{1}{2\pi \sqrt{LC}}$$

where f is the frequency in hertz, C is the capacitance in farads, L is the inductance in henries, and π is 3.14159.

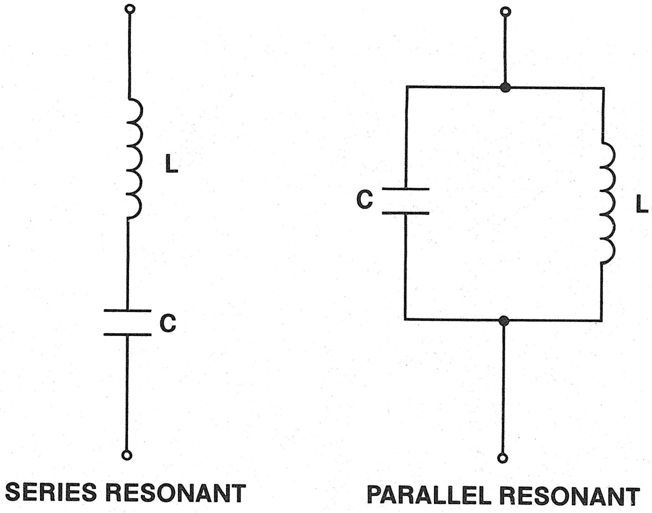


Figure 1-20. Series and Parallel Resonance

Impedance

When a circuit has both resistance and reactance, the combination of the two produces an opposition to current flow called impedance. Because of the effect of capacitive and inductive reactance, the current versus voltage relationship may vary between 0 and 90 degrees. Impedance formulas can be used for purely resistive circuits or circuits containing only capacitive or inductive reactance.

In a series circuit (see Figure 1-20) the formula for impedance is

$$Z = \sqrt{R^2 + X^2}$$

In a parallel circuit (Figure 1-20) the formula for impedance is

$$Z = \frac{RX}{\sqrt{R^2 + X^2}}$$

In both formulas, Z is the impedance in ohms, R is the resistance in ohms, and X is the reactance in ohms. When both capacitive and inductive reactance are present, the total reactance X is $X_L - X_C$, as the current in the two types of reactances is 180 degrees out of phase.

Example: Find the impedance of the circuit in Figure 1-21:

$$X = X_L - X_C = 6.3 - 15.9 = -9.6 \text{ ohms}$$

$$Z = \sqrt{(10 \times 10) + (-9.6 \times -9.6)} = \sqrt{100 + 92.2} = 13.9 \text{ ohms}$$

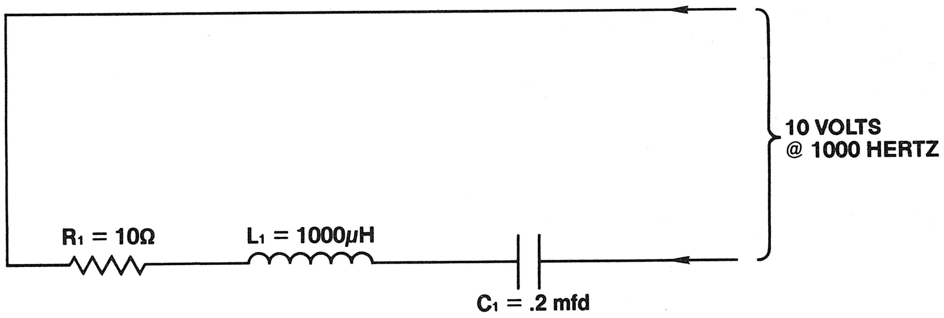


Figure 1-21. Impedance Example

The phase angle, the angle in degrees by which current leads voltage in a capacitive circuit or lags voltage in an inductive circuit, can be calculated by the relationship of resistance, reactance, and impedance.

$\varnothing = \arctan X/R$ $\varnothing = \arcsin X/Z$ $\varnothing = \arccos R/Z$

where arctan, arcsin, or arccos are read "the angle whose tangent (sine, cosine) is the value X/R (X/Z, R/Z). In a purely resistive circuit, there is no phase shift (the impedance is equal to the resistance). In a circuit where the combined effects of reactance is high compared to the resistance, the phase shift approaches 90 degrees.

Example: Find the phase shift of the circuit in Figure 1-21.

$\varnothing = \arctan 9.6/10 = 43.8$ degrees, current leading.

Ohms Law for Impedance

Impedance can be used in place of resistance to find the current or voltage in a circuit in Ohms Law:

$I = E/Z$ $E = IZ$ $Z = E/I$

where E is the electromotive force in volts, I is the current in amperes, and Z is the impedance in ohms.

Example: Find the current through the circuit of Figure 1-21.

$X_C = 15.9$ ohms
$X_L = 6.3$ ohms
$X = 6.3 - 15.9 = -9.6$ ohms
$Z = \sqrt{10^2 + -9.6^2} = 13.9$ ohms

$I = 10/13.9 = 0.72$ amperes

Only resistances in circuits containing reactances consume power. Apparent power consumed by the reactive components is measured in volt-amperes. The apparent power can be calculated by

$$P = I^2X$$

where P is the power in volt-amperes, I is the current in amperes, and X is the cumulative reactance in ohms.

Average, RMS, Peak, and Peak-to-Peak Voltage and Current

In a circuit in which a sine wave voltage or current appears, the peak-to-peak voltage or current, peak voltage or current, average voltage or current, and RMS voltage or current can be calculated as follows:

Given Average:

RMS = 1.112 x Average
Peak = 1.572 x Average
Peak-to-peak = 3.14 x Average

Given RMS:

Average = 0.899 x RMS
Peak = 1.414 x RMS
Peak-to-peak = 2.828 x RMS

Given Peak:

Average = 0.636 x Peak
RMS = 0.707 x Peak
Peak-to-peak = 2.0 x Peak

Given Peak-to-peak:

Average = 0.318 x Peak-to-peak
RMS = 0.3535 x Peak-to-peak
Peak = 0.5 x Peak

These relationships are shown in Figure 1-22. (The RMS value is the constant voltage or current which causes the same heating effect in a resistance.)

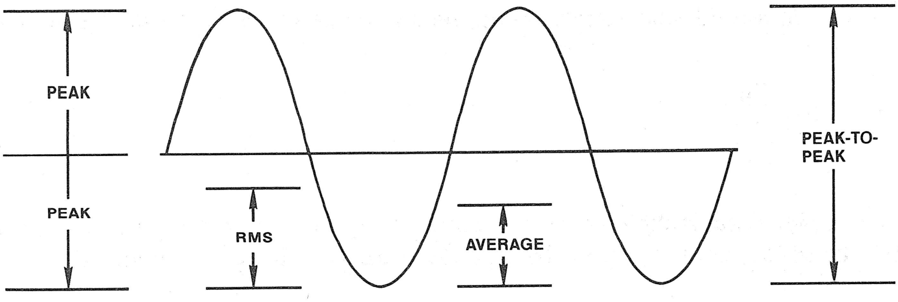


Figure 1-22. Average, RMS, Peak, and Peak-to-Peak Voltage and Current

Transformer Formulas

A transformer consists of two coils in very close proximity to each other, usually wound on the same core. When an alternating current is passed through the primary winding of the transformer (see Figure 1-23), a voltage is induced in the secondary winding as follows:

$$E_s = E_p \frac{n_s}{n_p}$$

where E_s and E_p are the secondary and primary voltages, respectively, and n_s and n_p are the secondary and primary turns on the coils.

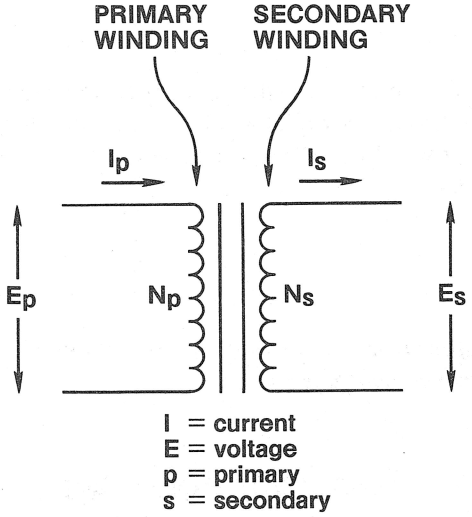


Figure 1-23. Transformer Relationships

The primary and secondary currents are also related by the turns ratio as follows:

$$I_s = I_p \frac{n_p}{n_s}$$

Example: What is the voltage induced in the secondary if the primary turns are 500, the secondary turns are 2500, and the primary voltage is 12 volts ac?

$$E_s = 12 \frac{2500}{500} = 12 \text{ x } 5 = 60 \text{ volts}$$

The impedances of the primary and secondary windings of an ideal transformer are also related by the turns ratio N_p/N_s.

$$Z_p = Z_s \left(\frac{n_p}{n_s}\right)^2$$

Example: An audio transformer that must connect an 8 ohm load with the 600 ohm output impedance of an audio amplifier stage would require a turns ratio of:

$$600 = 8 \left(\frac{n_p}{n_s}\right)^2$$

$$8.7 = \frac{n_p}{n_s}$$

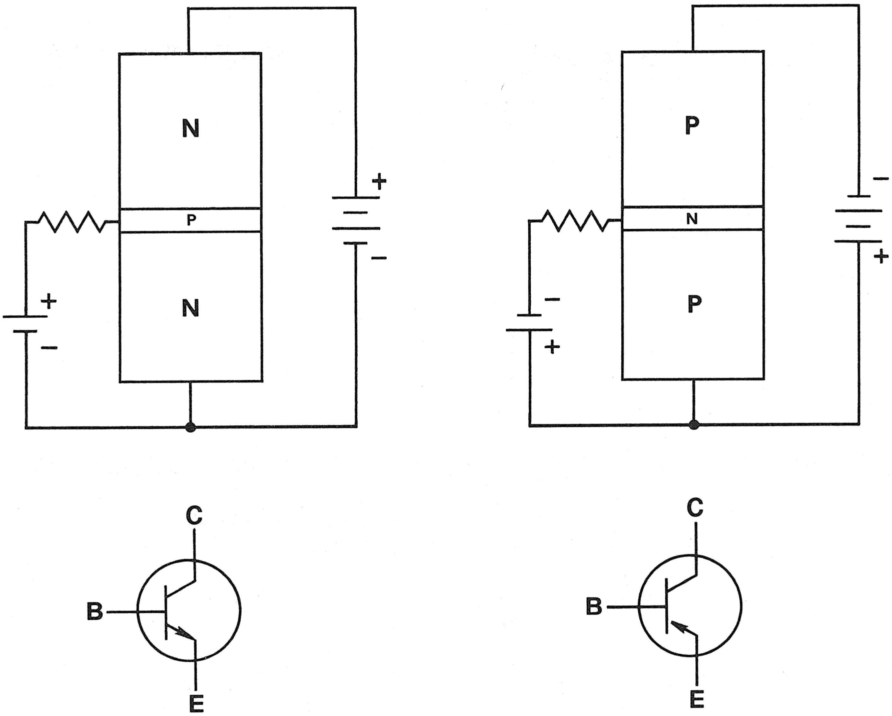
Transformers transfer power from the primary to the secondary but do not add power. Because of the resistance of the windings and other losses in the transformer core, there is some power loss in every transformer. The efficiency factor of a transformer is given by

$$n = \frac{P_s}{P_p}$$

where P_s is power output from the secondary and P_p is power input to the primary. The efficiency factor n is always less than 1.

Transistor Formulas

There are two basic types of transistors, an "NPN" type, consisting of a thin layer of "P" type material between two larger pieces of "N" type material, and a "PNP" type, of the opposite configuration, as shown in Figure 1-24. Electrons in the NPN type, or "holes" in the PNP type, flow between the outer material layers when the transistor is suitably biased with an external voltage. The inner layer is a "base" layer, while the outer layer which emits electrons or holes is called an "emitter" and the outer layer which collects the electrons or holes is called a "collector." A small base current can control a much larger emitter/collector current, making the transister an amplifying device.



NPN TRANSISTOR

PNP TRANSISTOR

Figure 1-24. Transistor Types

In all cases, the current through the emitter equals the current through the collector plus the current through the base:

$$I_e = I_c + I_b$$

There are three common configurations of transistor circuits, shown in Figure 1-25, the common emitter, the common base, and common collector. The "common" adjective refers to which element of the transistor is common to both input and output.

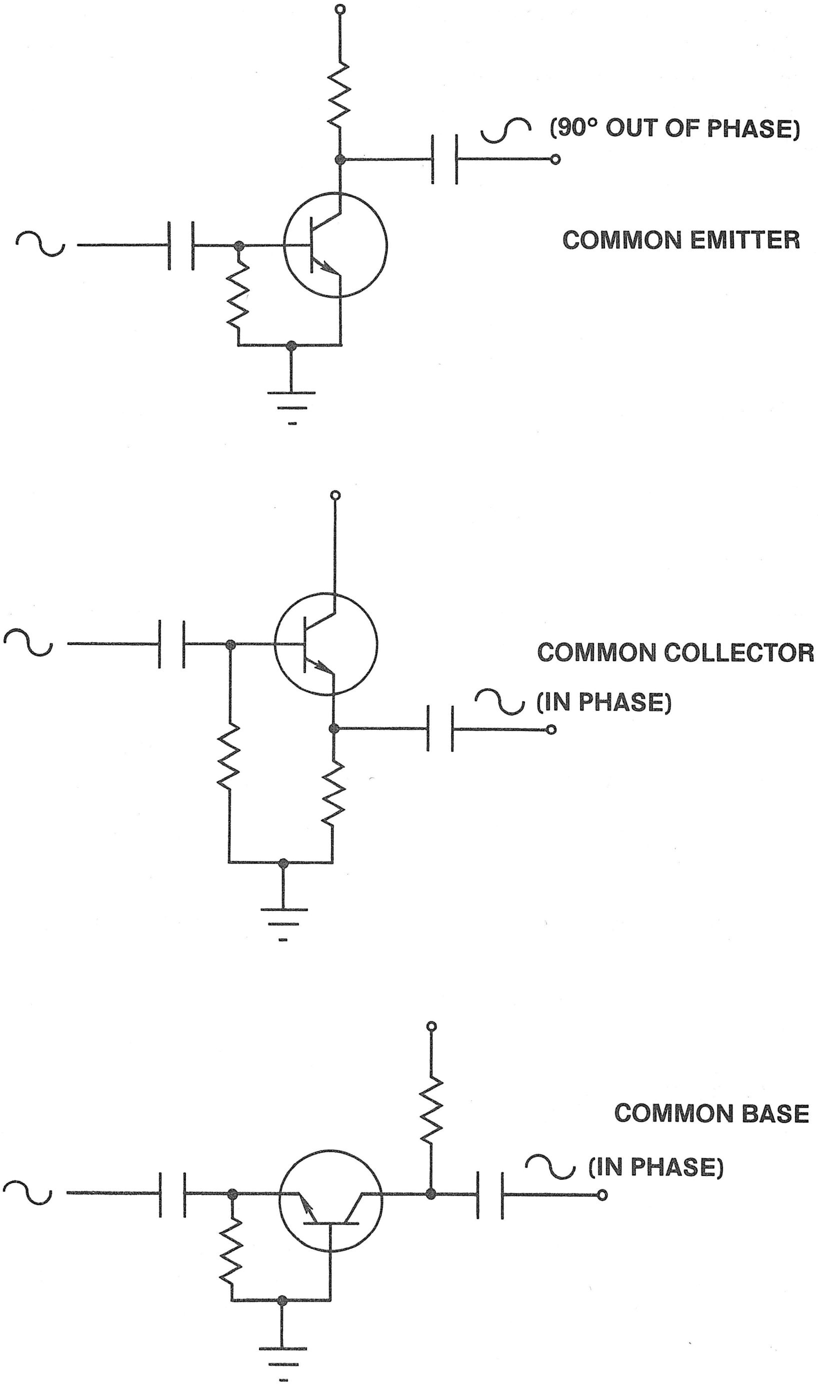


Figure 1-25. Transistor Circuit Configurations

A transistor, unlike a vacuum tube, is a current amplifying device. The most important parameter describing the amplifying capability of a transistor in common emitter configuration is beta, represented by the Greek letter ß.

$$\beta = I_c/I_b$$

Beta is the increase in base current divided into the resulting increase in collector current. Typical betas are 10 to 200.

Current gain of a transistor in the common-base configuration is designated alpha, represented by the Greek letter ∝.

$$\alpha = I_c/I_e$$

where alpha is the increase in emitter current divided into the resulting increase in collector current.

There is a direct relationship between beta and alpha given by

$$\alpha = \frac{\beta}{1 + \beta} \qquad \beta = \frac{\alpha}{1 - \alpha}$$

The higher the beta parameter, the closer alpha will be to 1. Alpha can never exceed a value of 1. A transistor with a beta of 25, for example, will have an alpha of

$$\alpha = \frac{25}{1 + 25} = 25/26 = .96$$

The common base configuration is characterized by low input impedance and high output impedance. There is no current gain but moderate power gain.

The common collector configuration is characterized by high input impedance and low output impedance. There is no voltage gain but moderate power gain.

The common emitter configuration is characterized by moderately low input and output impedance and current and power gain.

Operational Amplifier Formulas and Configurations

An operational amplifier is (usually) an analog integrated circuit used for addition, subtraction, integration, differentiation, and many other practical applications. Typical operational amplifiers, or "op amps" have very high input impedance, the potential of very high gains, very high bandwidth, and low output impedance.

Since the characteristics of the op amp circuit is largely determined by external components, op amps offer ease of use and design. Figure 1-26 shows common op amp configurations and formulas for typical op amp integrated circuits.

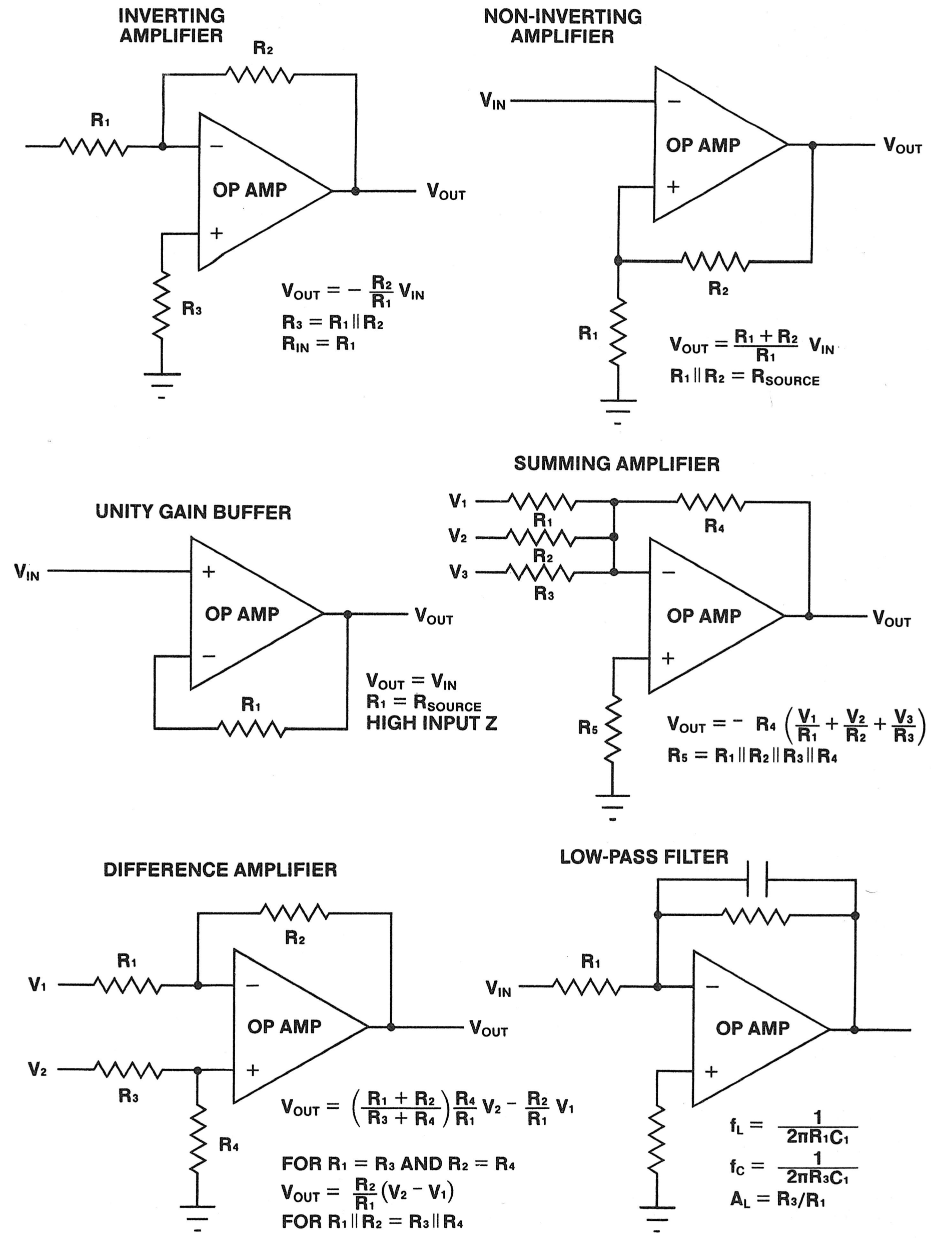

INVERTING AMPLIFIER
R2
R1
OP AMP
VOUT
R3
$V_{OUT} = -\frac{R_2}{R_1} V_{IN}$
$R_3 = R_1 \| R_2$
$R_{IN} = R_1$
NON-INVERTING AMPLIFIER
VIN
OP AMP
VOUT
R2
R1
$V_{OUT} = \frac{R_1 + R_2}{R_1} V_{IN}$
$R_1 \| R_2 = R_{SOURCE}$
UNITY GAIN BUFFER
VIN
OP AMP
VOUT
R1
$V_{OUT} = V_{IN}$
$R_1 = R_{SOURCE}$
HIGH INPUT Z
SUMMING AMPLIFIER
V1
V2
V3
R1
R2
R3
R4
OP AMP
VOUT
R5
$V_{OUT} = -R_4 \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$
$R_5 = R_1 \| R_2 \| R_3 \| R_4$
DIFFERENCE AMPLIFIER
R1
V1
V2
R2
R3
R4
OP AMP
VOUT
$V_{OUT} = \left(\frac{R_1 + R_2}{R_3 + R_4}\right) \frac{R_4}{R_1} V_2 - \frac{R_2}{R_1} V_1$
FOR $R_1 = R_3$ AND $R_2 = R_4$
$V_{OUT} = \frac{R_2}{R_1}(V_2 - V_1)$
FOR $R_1 \| R_2 = R_3 \| R_4$
LOW-PASS FILTER
R1
VIN
OP AMP
$f_L = \frac{1}{2\pi R_1 C_1}$
$f_C = \frac{1}{2\pi R_3 C_1}$
$A_L = R_3/R_1$

Figure 1-26. Common Operational Amplifier Configurations

Frequency and Wavelength

The distance between the same parts of a waveform, crest to crest, trough to trough, or zero crossing to zero crossing, determines the frequency of the waveform, expressed in cycles per second or hertz.

Frequencies above about 15000 hertz are known as radio frequencies. Multiples of 1,000 hertz use kilohertz (kHz) units, multiples of 1,000,000 hertz use megahertz (MHz) units, and multiples of 1,000,000,000 hertz use gigahertz (GHz) units.

Radio frequency waves travel at the same speed as light waves, about 299,793,000 meters per second. Wavelength, the distance that a radio frequency wave travels during one complete cycle, is the reciprocal of frequency. A radio wave with a frequency of 299,793,000 hertz would travel one meter in one cycle. The general formula relating frequency and wavelength is

$$f = \frac{299{,}793{,}000}{\lambda} \qquad \lambda = \frac{299{,}793{,}000}{f}$$

where f is the frequency in hertz and λ is the wavelength in meters.

For frequencies in kilohertz,

$$f = \frac{299{,}793}{\lambda} \qquad \lambda = \frac{299{,}793}{f}$$

For frequencies in megahertz,

$$f = \frac{299.793}{\lambda} \qquad \lambda = \frac{299.793}{f}$$

For frequencies in megahertz and wavelength in feet,

$$f = \frac{983.6}{\lambda} \qquad \lambda = \frac{983.6}{f}$$

Table 1-1 shows frequency versus wavelength in meters and feet for frequencies from 30 kHz to 3000 MHz.

Table 1-1. Frequency/Wavelength Conversion

kHz	Mtrs	MHz	Mtrs	MHz	Mtrs	MHz	Mtrs	MHz	Cm
30	9993.1	0.30	999.9	3.0	100.0	30	10.00	300	99.99
31	9670.7	0.31	967.7	3.1	96.8	31	9.68	310	96.77
32	9368.5	0.32	937.4	3.2	93.7	32	9.37	320	93.74
33	9084.6	0.33	909.0	3.3	90.9	33	9.09	330	90.90
34	8817.4	0.34	882.3	3.4	88.2	34	8.82	340	88.23
35	8565.5	0.35	857.1	3.5	85.7	35	8.57	350	85.71
36	8327.6	0.36	833.3	3.6	83.3	36	8.33	360	83.33
37	8102.5	0.37	810.8	3.7	81.1	37	8.11	370	81.08
38	7889.3	0.38	789.4	3.8	78.9	38	7.89	380	78.94

Table 1-1. Frequency/Wavelength Conversion (Cont.)

kHz	Mtrs	MHz	Mtrs	MHz	Mtrs	MHz	Mtrs	MHz	Cm
39	7687.0	0.39	769.2	3.9	76.9	39	7.69	390	76.92
40	7494.8	0.40	749.9	4.0	75.0	40	7.50	400	74.99
50	5995.9	0.50	600.0	5.0	60.0	50	6.00	500	60.00
60	4996.6	0.60	500.0	6.0	50.0	60	5.00	600	50.00
70	4282.8	0.70	428.5	7.0	42.9	70	4.29	700	42.85
80	3747.4	0.80	375.0	8.0	37.5	80	3.75	800	37.50
90	3331.0	0.90	333.3	9.0	33.3	90	3.33	900	33.33
100	2997.9	1.00	300.0	10.0	30.0	100	3.00	1000	30.00
110	2725.4	1.10	272.7	11.0	27.3	110	2.73	1100	27.27
120	2498.3	1.20	250.0	12.0	25.0	120	2.50	1200	25.00
130	2306.1	1.30	230.8	13.0	23.1	130	2.31	1300	23.08
140	2141.4	1.40	214.3	14.0	21.4	140	2.14	1400	21.43
150	1998.6	1.50	200.0	15.0	20.0	150	2.00	1500	20.00
160	1873.7	1.60	187.5	16.0	18.7	160	1.87	1600	18.75
170	1763.5	1.70	176.5	17.0	17.6	170	1.76	1700	17.65
180	1665.5	1.80	166.7	18.0	16.7	180	1.67	1800	16.67
190	1577.9	1.90	157.9	19.0	15.8	190	1.58	1900	15.79
200	1499.0	2.00	150.0	20.0	15.0	200	1.50	2000	15.00
210	1427.6	2.10	142.8	21.0	14.3	210	1.43	2100	14.28
220	1362.7	2.20	136.4	22.0	13.6	220	1.36	2200	13.64
230	1303.4	2.30	130.4	23.0	13.0	230	1.30	2300	13.04
240	1249.1	2.40	125.0	24.0	12.5	240	1.25	2400	12.50
250	1199.2	2.50	120.0	25.0	12.0	250	1.20	2500	12.00
260	1153.1	2.60	115.4	26.0	11.5	260	1.15	2600	11.54
270	1110.3	2.70	111.1	27.0	11.1	270	1.11	2700	11.11
280	1070.7	2.80	107.1	28.0	10.7	280	1.07	2800	10.71
290	1033.8	2.90	103.4	29.0	10.3	290	1.03	2900	10.34
300	999.3	3.00	100.0	30.0	10.0	300	1.00	3000	10.00

Transmission Line Formulas

Transmission lines are used to transmit electromagnetic energy over long distances with little loss of energy. Transmission lines are typically used in connecting radio-frequency antennas to a receiver, transmitter, or both. Common types of transmission lines are coaxial line, which is a center-conductor/shielded type of line, or a parallel conductor line, made up of two conductors separated from each other by a constant distance.

A transmission line has a characteristic velocity factor relating to the speed of transmission of electromagnetic energy through the line. The velocity factor is always less than one, and must be taken into account when cutting lines to specific wavelengths (a 300-ohm twin lead line, for example, typically has a velocity factor of .82, making a 10 MHz quarter wave section of the line 24.6 x .82 = 20.2 feet instead of 24.6 feet.)

The characteristic impedance of a coaxial line is given by

$$Z = \frac{138}{\sqrt{k}} \log \frac{D}{d}$$

where Z is the characteristic impedance, D is the inside diameter of the outer conductor, d is the outside diameter of the inner conductor (same units as D), and k is the dielectric constant of the insulting material, as shown in Figure 1-27. (The constant k is 1 for air and greater than 1 for common types of insulating materials - see section 6).

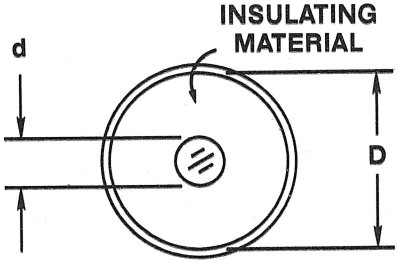


Figure 1-27. Coaxial Line

For a parallel conductor line, shown in Figure 1-28, the characteristic impedance is

$$Z = \frac{276}{\sqrt{k}} \log \frac{2D}{d}$$

where D is the center-to-center distance between the conductors, d is the diameter of the conductors (same units as D), and k is the dielectric constant of the insulating material. (The constant k is 1 for an "open-wire" line with air as the insulator.)

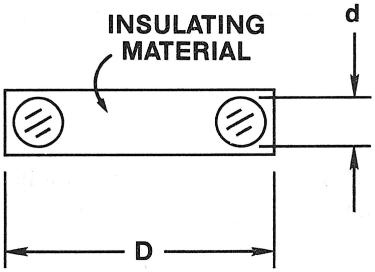


Figure 1-28. Parallel-Conductor Line

Coil Windings

The inductance of a cylindrical single-layer coil wound on an insulating form (or self supporting) is given by

$$L = \frac{r^2N^2}{9r + 10l}$$

where L is the inductance in microhenries, N is the number of turns, r is the radius in inches, and l is the length of the winding, as shown in Figure 1-29.

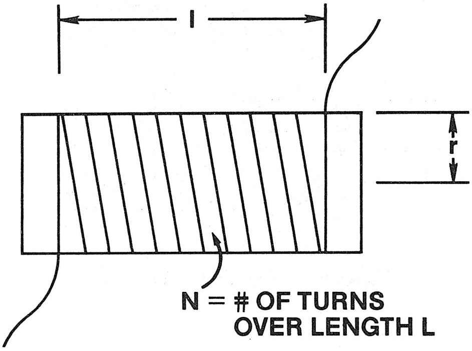


Figure 1-29. Inductance of a Single-Layer Air Core Coil

This formula can be transposed to find the number of turns required for a given inductance:

$$n = \sqrt{\frac{L(9r + 10l)}{r^2}}$$

The inductance of a multi-layer air core coil is given by

$$L = \frac{0.8(r^2n^2)}{6r + 9l + 10h}$$

where L is the inductance in microhenries, n is the number of turns, r is the radius in inches, l is the length of the winding, and h is the depth of the winding, as shown in Figure 1-30.

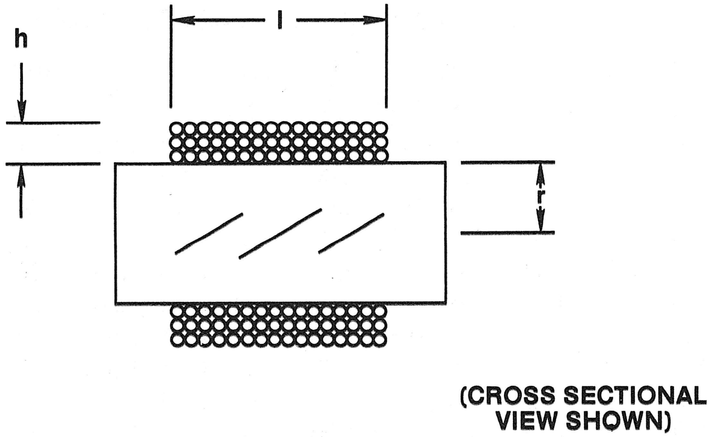


Figure 1-30. Inductance of a Multi-Layer Air Core Coil

The turns required for a given inductance of a toroidal coil requires a figure called the inductance index of the toroidal coil. The inductance index depends upon the size of the toroid and the permeability (ratio of magnetization and flux density) of the toroid material. The inductance index is included in the toroid manufacturer's data sheets. The formula for the number of turns is

$$n = 100 \quad \sqrt{L / A_l}$$

where n is the number of turns, L is the inductance in microhenries, and A_l is the inductance index. Typical inductance indices range from 10 to 3000.

Table 1-2 shows single-layer coil data for inductances of 0.1 to 9000 μH. For each inductance value, the number of turns required for diameters of 1/4 inch, 1/2 inch, 3/4 inch, and 1 inch forms are given. The coil winding length is twice the diameter in all cases. Turns are given to the nearest turn. Other cases can be interpolated from the data in the table - for example a coil with 250 μH inductance would be approximately 220 turns of a 1/2 inch diameter, 1 inch length coil.

Table 1-2. Single-Layer Coil Chart

μH	D	L	Turns	D	L	Turns	D	L	Turns	D	L	Turns
0.1	0.25	0.50	6	0.50	1.00	4	0.75	1.50	4	1.00	2.00	3
0.2	0.25	0.50	9	0.50	1.00	6	0.75	1.50	5	1.00	2.00	4
0.3	0.25	0.50	11	0.50	1.00	8	0.75	1.50	6	1.00	2.00	5
0.4	0.25	0.50	13	0.50	1.00	9	0.75	1.50	7	1.00	2.00	6
0.5	0.25	0.50	14	0.50	1.00	10	0.75	1.50	8	1.00	2.00	7
0.6	0.25	0.50	15	0.50	1.00	11	0.75	1.50	9	1.00	2.00	8
0.7	0.25	0.50	17	0.50	1.00	12	0.75	1.50	10	1.00	2.00	8
0.8	0.25	0.50	18	0.50	1.00	13	0.75	1.50	10	1.00	2.00	9

Table 1-2. Single-Layer Coil Chart (Cont.)

μH	D	L	Turns	D	L	Turns	D	L	Turns	D	L	Turns
0.9	0.25	0.50	19	0.50	1.00	13	0.75	1.50	11	1.00	2.00	9
1.0	0.25	0.50	20	0.50	1.00	14	0.75	1.50	11	1.00	2.00	10
2.0	0.25	0.50	28	0.50	1.00	20	0.75	1.50	16	1.00	2.00	14
3.0	0.25	0.50	34	0.50	1.00	24	0.75	1.50	20	1.00	2.00	17
4.0	0.25	0.50	40	0.50	1.00	28	0.75	1.50	23	1.00	2.00	20
5.0	0.25	0.50	44	0.50	1.00	31	0.75	1.50	26	1.00	2.00	22
6.0	0.25	0.50	48	0.50	1.00	34	0.75	1.50	28	1.00	2.00	24
7.0	0.25	0.50	52	0.50	1.00	37	0.75	1.50	30	1.00	2.00	26
8.0	0.25	0.50	56	0.50	1.00	40	0.75	1.50	32	1.00	2.00	28
9.0	0.25	0.50	59	0.50	1.00	42	0.75	1.50	34	1.00	2.00	30
10.0	0.25	0.50	63	0.50	1.00	44	0.75	1.50	36	1.00	2.00	31
20.0	0.25	0.50	89	0.50	1.00	63	0.75	1.50	51	1.00	2.00	44
30.0	0.25	0.50	108	0.50	1.00	77	0.75	1.50	63	1.00	2.00	54
40.0	0.25	0.50	125	0.50	1.00	89	0.75	1.50	72	1.00	2.00	63
50.0	0.25	0.50	140	0.50	1.00	99	0.75	1.50	81	1.00	2.00	70
60.0	0.25	0.50	153	0.50	1.00	108	0.75	1.50	89	1.00	2.00	77
70.0	0.25	0.50	166	0.50	1.00	117	0.75	1.50	96	1.00	2.00	83
80.0	0.25	0.50	177	0.50	1.00	125	0.75	1.50	102	1.00	2.00	89
90.0	0.25	0.50	188	0.50	1.00	133	0.75	1.50	108	1.00	2.00	94
100.0	0.25	0.50	198	0.50	1.00	140	0.75	1.50	114	1.00	2.00	99
200.0	0.25	0.50	280	0.50	1.00	198	0.75	1.50	162	1.00	2.00	140
300.0	0.25	0.50	343	0.50	1.00	242	0.75	1.50	198	1.00	2.00	171
400.0	0.25	0.50	396	0.50	1.00	280	0.75	1.50	229	1.00	2.00	198
500.0	0.25	0.50	443	0.50	1.00	313	0.75	1.50	256	1.00	2.00	221
600.0	0.25	0.50	485	0.50	1.00	343	0.75	1.50	280	1.00	2.00	242
700.0	0.25	0.50	524	0.50	1.00	370	0.75	1.50	302	1.00	2.00	262
800.0	0.25	0.50	560	0.50	1.00	396	0.75	1.50	323	1.00	2.00	280
900.0	0.25	0.50	594	0.50	1.00	420	0.75	1.50	343	1.00	2.00	297
1000.0	0.25	0.50	626	0.50	1.00	443	0.75	1.50	361	1.00	2.00	313
2000.0	0.25	0.50	885	0.50	1.00	626	0.75	1.50	511	1.00	2.00	443
3000.0	0.25	0.50	1084	0.50	1.00	767	0.75	1.50	626	1.00	2.00	542
4000.0	0.25	0.50	1252	0.50	1.00	885	0.75	1.50	723	1.00	2.00	626
5000.0	0.25	0.50	1400	0.50	1.00	990	0.75	1.50	808	1.00	2.00	700
6000.0	0.25	0.50	1534	0.50	1.00	1084	0.75	1.50	885	1.00	2.00	767
7000.0	0.25	0.50	1657	0.50	1.00	1171	0.75	1.50	956	1.00	2.00	828
8000.0	0.25	0.50	1771	0.50	1.00	1252	0.75	1.50	1022	1.00	2.00	885
9000.0	0.25	0.50	1878	0.50	1.00	1328	0.75	1.50	1084	1.00	2.00	939

Time Constant

When a capacitor or inductor is connected to a source of voltage through a resistance, the time for the capacitor to charge and the time for the current to reach full value through the inductor is determined by the following equations

For Resistor/Capacitor:

$$V_t = E\left(1 - e^{\frac{-t}{RC}}\right)$$

For Resistor/Inductor:

$$I_t = \frac{E}{R}\left(1 - e^{\frac{tR}{L}}\right)$$

where V_t is the voltage across the capacitor, I_t is the current through the inductor, R is the resistance in ohms, C is the capacitance in farads, L is the inductance in henries, t is the time in seconds, and e is the natural log constant 2.71828.

The product of R times C or R divided by L is the time constant of the circuit. One time constant is equal to the time in seconds to charge the capacitor to 63.2% of the final charge or for the current through the inductor to reach 63.2% of its final value. After another time constant, an additional 63.2% of the *remaining* charge or current will be reached. The time constant also affects the discharge of a capacitor or decay of current in an inductor when the circuit is broken. Figure 1-31 shows the effects of time constants up to 3 and plots the voltage or current as a function of time for a constant RC product.

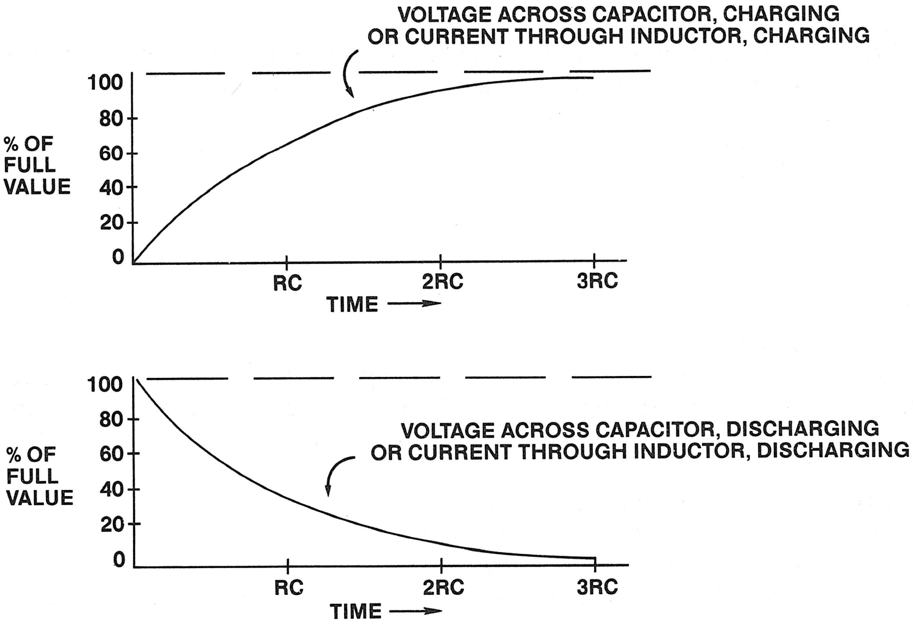


Figure 1-31. Time Constant Plots

Decibel Equations

The relative loudness of audio signal strength is referenced to the human ear and measured in *decibel* units. One decibel corresponds to a change in power level that can just be detected under perfect conditions.

Power Ratios

If P_1 is a starting power level and P_2 is the ending power level, the gain or loss in decibels is given by

$$dB = 10 \log \frac{P_2}{P_1}$$

where the base used for the logarithm is base 10.

Example: Doubling the power of a signal from 20 to 40 watts causes about a 3 dB gain; halving the power causes about a 3 dB loss:

$$dB = 10 \log \frac{40}{20} = 10 \log 2 = 3.01$$

$$dB = 10 \log \frac{20}{40} = 10 \log \frac{1}{2} = -3.01$$

Voltage and Current Ratios

When voltage and current is used in place of power and both signals are measured across the same value of impedance, the formula becomes:

$$dB = 20 \log \frac{E_2}{E_1}$$

$$dB = 20 \log \frac{I_2}{I_1}$$

Reference Levels

Levels are often expressed with only the ending power, voltage, or current given; the other level is understood to be a standard reference level. Common reference levels are:

dBW	decibels referenced to 1 watt
dBm	decibels referenced to 1 milliwatt
dBV	decibels referenced to 1 volt
VU	decibels referenced to 1 milliwatt, across 600 ohms, audio signals

Table of Values

Table 1-3 gives the power, voltage, and current ratios for both gains and losses, cross referenced to decibels. A power gain of 2.754, for example (column two) is equal to a gain of 4.4 dB. Conversely, a voltage ratio increase of 1.500 is equivalent to an increase of about 3.6 dB. Intermediate ratios can be interpolated to find the equivalent decibels. Decibels from 0 through 19.9 can be read directly from the table.

Table 1-3. Decibels Vs. Power and E/I Ratios

	Power Ratio		I/E Ratio		20 - 99.9 db			
dB	Gain	Loss	Gain	Loss	20	40	60	80
.0	1.000	1.000	1.000	1.0000	20.0	40.1	60.0	80.0
.1	1.023	.9772	1.012	.9886	20.1	40.1	60.1	80.1
.2	1.047	.9550	1.023	.9772	20.2	40.2	60.2	80.2
.3	1.072	.9333	1.035	.9661	20.3	40.3	60.3	80.3
.4	1.096	.9120	1.047	.9550	20.4	40.4	60.4	80.4
.5	1.122	.8913	1.059	.9441	20.5	40.5	60.5	80.5
.6	1.148	.8710	1.072	.9333	20.6	40.6	60.6	80.6
.7	1.175	.8511	1.084	.9226	20.7	40.7	60.7	80.7
.8	1.202	.8318	1.096	.9120	20.8	40.8	60.8	80.8
.9	1.230	.8128	1.109	.9016	20.9	40.9	60.9	80.9
1.0	1.259	.7943	1.122	.8913	21.0	41.0	61.0	81.0
1.1	1.288	.7762	1.135	.8810	21.1	41.1	61.1	81.1
1.2	1.318	.7586	1.148	.8710	21.2	41.2	61.2	81.2
1.3	1.349	.7413	1.161	.8610	21.3	41.3	61.3	81.3
1.4	1.380	.7244	1.175	.8511	21.4	41.4	61.4	81.4
1.5	1.413	.7079	1.189	.8414	21.5	41.5	61.5	81.5
1.6	1.445	.6918	1.202	.8318	21.6	41.6	61.6	81.6
1.7	1.479	.6761	1.216	.8222	21.7	41.7	61.7	81.7
1.8	1.514	.6607	1.230	.8128	21.8	41.8	61.8	81.8
1.9	1.549	.6457	1.245	.8035	21.9	41.9	61.9	81.9
2.0	1.585	.6310	1.259	.7943	22.0	42.0	62.0	82.0
2.1	1.622	.6166	1.274	.7852	22.1	42.1	62.1	82.1
2.2	1.660	.6026	1.288	.7762	22.2	42.2	62.2	82.2
2.3	1.698	.5888	1.303	.7674	22.3	42.3	62.3	82.3
2.4	1.738	.5754	1.318	.7586	22.4	42.4	62.4	82.4
2.5	1.778	.5623	1.334	.7499	22.5	42.5	62.5	82.5
2.6	1.820	.5495	1.349	.7413	22.6	42.6	62.6	82.6
2.7	1.862	.5370	1.365	.7328	22.7	42.7	62.7	82.7
2.8	1.905	.5248	1.380	.7244	22.8	42.8	62.8	82.8
2.9	1.950	.5129	1.396	.7161	22.9	42.9	62.9	82.9
3.0	1.995	.5012	1.413	.7079	23.0	43.0	63.0	83.0
3.1	2.042	.4898	1.429	.6998	23.1	43.1	63.1	83.1
3.2	2.089	.4786	1.445	.6918	23.2	43.2	63.2	83.2
3.3	2.138	.4677	1.462	.6839	23.3	43.3	63.3	83.3

Table 1-3. Decibels Vs. Power and E/I Ratios (Cont.)

	Power Ratio		I/E Ratio		20 - 99.9 db			
dB	Gain	Loss	Gain	Loss	20	40	60	80
3.4	2.188	.4571	1.479	.6761	23.4	43.4	63.4	83.4
3.5	2.239	.4467	1.496	.6683	23.5	43.5	63.5	83.5
3.6	2.291	.4365	1.514	.6607	23.6	43.6	63.6	83.6
3.7	2.344	.4266	1.531	.6531	23.7	43.7	63.7	83.7
3.8	2.399	.4169	1.549	.6457	23.8	43.8	63.8	83.8
3.9	2.455	.4074	1.567	.6383	23.9	43.9	63.9	83.9
4.0	2.512	.3981	1.585	.6310	24.0	44.0	64.0	84.0
4.1	2.570	.3890	1.603	.6237	24.1	44.1	64.1	84.1
4.2	2.630	.3802	1.622	.6166	24.2	44.2	64.2	84.2
4.3	2.692	.3715	1.641	.6095	24.3	44.3	64.3	84.3
4.4	2.754	.3631	1.660	.6026	24.4	44.4	64.4	84.4
4.5	2.818	.3548	1.679	.5957	24.5	44.5	64.5	84.5
4.6	2.884	.3467	1.698	.5888	24.6	44.6	64.6	84.6
4.7	2.951	.3388	1.718	.5821	24.7	44.7	64.7	84.7
4.8	3.020	.3311	1.738	.5754	24.8	44.8	64.8	84.8
4.9	3.090	.3236	1.758	.5689	24.9	44.9	64.9	84.9
5.0	3.162	.3162	1.778	.5623	25.0	45.0	65.0	85.0
5.1	3.236	.3090	1.799	.5559	25.1	45.1	65.1	85.1
5.2	3.311	.3020	1.820	.5495	25.2	45.2	65.2	85.2
5.3	3.388	.2951	1.841	.5433	25.3	45.3	65.3	85.3
5.4	3.467	.2884	1.862	.5370	25.4	45.4	65.4	85.4
5.5	3.548	.2818	1.884	.5309	25.5	45.5	65.5	85.5
5.6	3.631	.2754	1.905	.5248	25.6	45.6	65.6	85.6
5.7	3.715	.2692	1.928	.5188	25.7	45.7	65.7	85.7
5.8	3.802	.2630	1.950	.5129	25.8	45.8	65.8	85.8
5.9	3.890	.2570	1.972	.5070	25.9	45.9	65.9	85.9
6.0	3.981	.2512	1.995	.5012	26.0	46.0	66.0	86.0
6.1	4.074	.2455	2.018	.4955	26.1	46.1	66.1	86.1
6.2	4.169	.2399	2.042	.4898	26.2	46.2	66.2	86.2
6.3	4.266	.2344	2.065	.4842	26.3	46.3	66.3	86.3
6.4	4.365	.2291	2.089	.4786	26.4	46.4	66.4	86.4
6.5	4.467	.2239	2.113	.4732	26.5	46.5	66.5	86.5
6.6	4.571	.2188	2.138	.4677	26.6	46.6	66.6	86.6
6.7	4.677	.2138	2.163	.4624	26.7	46.7	66.7	86.7
6.8	4.786	.2089	2.188	.4571	26.8	46.8	66.8	86.8
6.9	4.898	.2042	2.213	.4519	26.9	46.9	66.9	86.9
7.0	5.012	.1995	2.239	.4467	27.0	47.0	67.0	87.0
7.1	5.129	.1950	2.265	.4416	27.1	47.1	67.1	87.1
7.2	5.248	.1905	2.291	.4365	27.2	47.2	67.2	87.2
7.3	5.370	.1862	2.317	.4315	27.3	47.3	67.3	87.3
7.4	5.495	.1820	2.344	.4266	27.4	47.4	67.4	87.4
7.5	5.623	.1778	2.371	.4217	27.5	47.5	67.5	87.5

Table 1-3. Decibels Vs. Power and E/I Ratios (Cont.)

	Power Ratio		I/E Ratio		20 - 99.9 db			
dB	Gain	Loss	Gain	Loss	20	40	60	80
7.6	5.754	.1738	2.399	.4169	27.6	47.6	67.6	87.6
7.7	5.888	.1698	2.427	.4121	27.7	47.7	67.7	87.7
7.8	6.026	.1660	2.455	.4074	27.8	47.8	67.8	87.8
7.9	6.166	.1622	2.483	.4027	27.9	47.9	67.9	87.9
8.0	6.310	.1585	2.512	.3981	28.0	48.0	68.0	88.0
8.1	6.457	.1549	2.541	.3936	28.1	48.1	68.1	88.1
8.2	6.607	.1514	2.570	.3890	28.2	48.2	68.2	88.2
8.3	6.761	.1479	2.600	.3846	28.3	48.3	68.3	88.3
8.4	6.918	.1445	2.630	.3802	28.4	48.4	68.4	88.4
8.5	7.079	.1413	2.661	.3758	28.5	48.5	68.5	88.5
8.6	7.244	.1380	2.692	.3715	28.6	48.6	68.6	88.6
8.7	7.413	.1349	2.723	.3673	28.7	48.7	68.7	88.7
8.8	7.586	.1318	2.754	.3631	28.8	48.8	68.8	88.8
8.9	7.762	.1288	2.786	.3589	28.9	48.9	68.9	88.9
9.0	7.943	.1259	2.818	.3548	29.0	49.0	69.0	89.0
9.1	8.128	.1230	2.851	.3508	29.1	49.1	69.1	89.1
9.2	8.318	.1202	2.884	.3467	29.2	49.2	69.2	89.2
9.3	8.511	.1175	2.917	.3428	29.3	49.3	69.3	89.3
9.4	8.710	.1148	2.951	.3388	29.4	49.3	69.4	89.4
9.5	8.913	.1122	2.985	.3350	29.5	49.5	69.5	89.5
9.6	9.120	.1096	3.020	.3311	29.6	49.6	69.6	89.6
9.7	9.333	.1072	3.055	.3273	29.7	49.7	69.7	89.7
9.8	9.550	.1047	3.090	.3236	29.8	49.8	69.8	89.8
9.9	9.772	.1023	3.126	.3199	29.9	49.9	69.9	89.9
10.0	10.00	.1000	3.162	.3162	30.0	50.0	70.0	90.0
10.1	10.23	.0977	3.199	.3126	30.1	50.1	70.1	90.1
10.2	10.47	.0955	3.236	.3090	30.2	50.2	70.2	90.2
10.3	10.72	.0933	3.273	.3055	30.3	50.3	70.3	90.3
10.4	10.96	.0912	3.311	.3020	30.4	50.4	70.4	90.4
10.5	11.22	.0891	3.350	.2985	30.5	50.5	70.5	90.5
10.6	11.48	.0871	3.388	.2951	30.6	50.6	70.6	90.6
10.7	11.75	.0851	3.428	.2917	30.7	50.7	70.7	90.7
10.8	12.02	.0832	3.467	.2884	50.8	50.8	70.8	90.8
10.9	12.30	.0813	3.508	.2851	30.9	50.9	70.9	90.9
11.0	12.59	.0794	3.548	.2818	31.0	51.0	71.0	91.0
11.1	12.88	.0776	3.589	.2786	31.1	51.1	71.1	91.1
11.2	13.18	.0759	3.631	.2754	31.2	51.2	71.2	91.2
11.3	13.49	.0741	3.673	.2723	31.3	51.3	71.3	91.3
11.4	13.80	.0724	3.715	.2692	31.4	51.4	71.4	91.4
11.5	14.13	.0708	3.758	.2661	31.5	51.5	71.5	91.5
11.6	14.45	.0692	3.802	.2630	31.6	51.6	71.6	91.6
11.7	14.79	.0676	3.846	.2600	31.7	51.7	71.7	91.7

Table 1-3. Decibels Vs. Power and E/I Ratios (Cont.)

	Power Ratio		I/E Ratio		20 - 99.9 db			
dB	Gain	Loss	Gain	Loss	20	40	60	80
11.8	15.14	.0661	3.890	.2570	31.8	51.8	71.8	91.8
11.9	15.49	.0646	3.936	.2541	31.9	51.9	71.9	91.9
12.0	15.85	.0631	3.981	.2512	32.0	52.0	72.0	92.0
12.1	16.22	.0617	4.027	.2483	32.1	52.1	72.1	92.1
12.2	16.60	.0603	4.074	.2455	32.2	52.2	72.2	92.2
12.3	16.98	.0589	4.121	.2427	32.3	52.3	72.3	92.3
12.4	17.38	.0575	4.169	.2399	32.4	52.4	72.4	92.4
12.5	17.78	.0562	4.217	.2371	32.5	52.5	72.5	92.5
12.6	18.20	.0550	4.266	.2344	32.6	52.6	72.6	92.6
12.7	18.62	.0537	4.315	.2317	32.7	52.7	72.7	92.7
12.8	19.05	.0525	4.365	.2291	32.8	52.8	72.8	92.8
12.9	19.50	.0513	4.416	.2265	32.9	52.9	72.9	92.9
13.0	19.95	.0501	4.467	.2239	33.0	53.0	73.0	93.0
13.1	20.42	.0490	4.519	.2213	33.1	53.1	73.1	93.1
13.2	20.89	.0479	4.571	.2188	33.2	53.2	73.2	93.2
13.3	21.38	.0468	4.624	.2163	33.3	53.3	73.3	93.3
13.4	21.88	.0457	4.677	.2138	33.4	53.4	73.4	93.4
13.5	22.39	.0447	4.732	.2113	33.5	53.5	73.5	93.5
13.6	22.91	.0437	4.786	.2089	33.6	53.6	73.6	93.6
13.7	23.44	.0427	4.842	.2065	33.7	53.7	73.7	93.7
13.8	23.99	.0417	4.898	.2042	33.8	53.8	73.8	93.8
13.9	24.55	.0407	4.955	.2018	33.9	53.9	73.9	93.9
14.0	25.12	.0398	5.012	.1995	34.0	54.0	74.0	94.0
14.1	25.70	.0389	5.070	.1972	34.1	54.1	74.1	94.1
14.2	26.30	.0380	5.129	.1950	34.2	54.2	74.2	94.2
14.3	26.92	.0372	5.188	.1928	34.3	54.3	74.3	94.3
14.4	27.54	.0363	5.248	.1905	34.4	54.4	74.4	94.4
14.5	28.18	.0355	5.309	.1884	34.5	54.5	74.5	94.5
14.6	28.84	.0347	5.370	.1862	34.6	54.6	74.6	94.6
14.7	29.51	.0339	5.433	.1841	34.7	54.7	74.7	94.7
14.8	30.20	.0331	5.495	.1820	34.8	54.8	74.8	94.8
14.9	30.90	.0324	5.559	.1799	34.9	54.9	74.9	94.9
15.0	31.62	.0316	5.623	.1778	35.0	55.0	75.0	95.0
15.1	32.36	.0309	5.689	.1758	35.1	55.1	75.1	95.1
15.2	33.11	.0302	5.754	.1738	35.2	55.2	75.2	95.2
15.3	33.88	.0295	5.821	.1718	35.3	55.3	75.3	95.3
15.4	34.67	.0288	5.888	.1698	35.4	55.4	75.4	95.4
15.5	35.48	.0282	5.957	.1679	35.5	55.5	75.5	95.5
15.6	36.31	.0275	6.026	.1660	35.6	55.6	75.6	95.6
15.7	37.15	.0269	6.095	.1641	35.7	55.7	75.7	95.7
15.8	38.02	.0263	6.166	.1622	35.8	55.8	75.8	95.8
15.9	38.90	.0257	6.237	.1603	35.9	55.9	75.9	95.9

Table 1-3. Decibels Vs. Power and E/I Ratios (Cont.)

	Power Ratio		I/E Ratio		20 - 99.9 db			
dB	Gain	Loss	Gain	Loss	20	40	60	80
16.0	39.81	.0251	6.310	.1585	36.0	56.0	76.0	96.0
16.1	40.74	.0245	6.383	.1567	36.1	56.1	76.1	96.1
16.2	41.69	.0240	6.457	.1549	36.2	56.2	76.2	96.2
16.3	42.66	.0234	6.531	.1531	36.3	56.3	76.3	96.3
16.4	43.65	.0229	6.607	.1514	36.4	56.4	76.4	96.4
16.5	44.67	.0224	6.683	.1496	36.5	56.5	76.5	96.5
16.6	45.71	.0219	6.761	.1479	36.6	56.6	76.6	96.6
16.7	46.77	.0214	6.839	.1462	36.7	56.7	76.7	96.7
16.8	47.86	.0209	6.918	.1445	36.8	56.8	76.8	96.8
16.9	48.98	.0204	6.998	.1429	36.9	56.9	76.9	96.9
17.0	50.12	.0200	7.079	.1413	37.0	57.0	77.0	97.0
17.1	51.29	.0195	7.161	.1396	37.1	57.1	77.1	97.1
17.2	52.48	.0191	7.244	.1380	37.2	57.2	77.2	97.2
17.3	53.70	.0186	7.328	.1365	37.3	57.3	77.3	97.3
17.4	54.95	.0182	7.413	.1349	37.4	57.4	77.4	97.4
17.5	56.23	.0178	7.499	.1334	37.5	57.5	77.5	97.5
17.6	57.54	.0174	7.586	.1318	37.6	57.6	77.6	97.6
17.7	58.88	.0170	7.674	.1303	37.7	57.7	77.7	97.7
17.8	60.26	.0166	7.763	.1288	37.8	57.8	77.8	97.8
17.9	61.66	.0162	7.852	.1273	37.9	57.9	77.9	97.9
18.0	63.10	.0158	7.943	.1259	38.0	58.0	78.0	98.0
18.1	64.57	.0155	8.035	.1245	38.1	58.1	78.1	98.1
18.2	66.07	.0151	8.128	.1230	38.2	58.2	78.2	98.2
18.3	67.61	.0148	8.222	.1216	38.3	58.3	78.3	98.3
18.4	69.18	.0145	8.318	.1202	38.4	58.4	78.4	98.4
18.5	70.80	.0141	8.414	.1188	38.5	58.5	78.5	98.5
18.6	72.44	.0138	8.511	.1175	38.6	58.6	78.6	98.6
18.7	74.13	.0135	8.610	.1161	38.7	58.7	78.7	98.7
18.8	75.86	.0132	8.710	.1148	38.8	58.8	78.8	98.8
18.9	77.63	.0129	8.811	.1135	38.9	58.9	78.9	98.9
19.0	79.43	.0126	8.913	.1122	39.0	59.0	79.0	99.0
19.1	81.28	.0123	9.016	.1109	39.1	59.1	79.1	99.1
19.2	83.18	.0120	9.120	.1096	39.2	59.2	79.2	99.2
19.3	85.11	.0117	9.226	.1084	39.3	59.3	79.3	99.3
19.4	87.10	.0115	9.333	.1072	39.4	59.4	79.4	99.4
19.5	89.13	.0112	9.441	.1059	39.5	59.5	79.5	99.5
19.6	91.20	.0110	9.550	.1047	39.6	59.6	79.6	99.6
19.7	93.33	.0107	9.661	.1035	39.7	59.7	79.7	99.7
19.8	95.50	.0105	9.772	.1023	39.8	59.8	79.8	99.8
19.9	97.72	.0102	9.886	.1012	39.9	59.9	79.9	99.9

Decibels from 20.0 through 99.9 - Power Ratios

For decibels from 20.0 through 99.9, use the four columns on the extreme right of the table. To find the equivalent power ratios for a given gain or loss in decibels, first locate the decibel value in the four columns. Next, find the corresponding ratio. Finally multiply (gain) or divide (loss) by 100, 10,000, 1,000,000, or 100,000,000 depending upon whether the original decibel value was in the 20, 40, 60, or 80 column. For example, a gain of 44.5 decibels is required. The 44.5 value is found in the "40" column and the "4.5" row. The corresponding power ratio for the gain is 2.818. Multiplying this value by 10000 results in the final voltage ratio for 44.5 dB as 28180.

To find the change in dB for a given power ratio, find the ratio in the table, if possible. If the ratio is not in the table, multiply the ratio by 100, 10,000, 1,000,000 or 100,000,000 (gain) or divide the ratio by 100, 10,000, 1,000,000, or 100,000,000 (loss), each time looking for the result in the table. When found, read the equivalent change in dB from the 20 column (100 factor), 40 column (10,000 factor), 60 column (1,000,000 factor), or 80 column (100,000,000 factor). For example, assume a power loss of .0049 (1000 watts to 4.9 watts). The ratio .0049 is not in the table under "Power Ratio Loss." Multiply this value by 100, giving dB. Since a times 100 multiplier was used, read the change in dB under the "20" column - 43.1 dB.

Decibels from 20.0 through 99.9 - Voltage/Current Ratios

For decibels from 20.0 through 99.9, use the four columns on the extreme right of the table. To find the equivalent power ratios for a given gain or loss in decibels, first locate the decibel value in the four columns. Next, find the corresponding ratio. Finally multiply (gain) or divide (loss) by 10, 100, 1000, or 10000 depending upon whether the original decibel value was in the 20, 40, 60, or 80 column. For example, a gain of 44.5 decibels for a voltage level is required. The 44.5 value is found in the "40" column and the "4.5" row. The corresponding I/E ratio for a gain is 1.679. Multiplying this value by 100 results in the final voltage ratio for 44.5 dB as 167.9.

To find the change in dB for a given voltage/current ratio, find the ratio in the table, if possible. If the ratio is not in the table, multiply the ratio by 10, 100, 1000, or 10000 (gain) or divide (loss) the ratio by 10, 100, 1000, or 10000, each time looking for the result in the table. When found, read the equivalent change in dB from the 20 column (10 factor), 40 column (100 factor), 60 column (1000 factor), or 80 column (10000 factor). For example assume a power loss of .0035. The ratio .0035 is not in the table under "I/E Ratio Loss." Multiply this value by 100, giving .35. This approximate value is in the table opposite 9.1 dB. Since a times 100 multiplier was used, read the change in dB under the "40" column - 49.1 dB.

Section 2

Mathematical Tables and Formulas

Mathematical Constants

Figure 2-1. Mathematical Constants

$\pi = 3.141593$

$2\pi = 6.283186$

$4\pi = 12.56637$

$\frac{\pi}{2} = 1.570796$

$\frac{\pi}{4} = 0.7853982$

$\frac{1}{\pi} = 0.3183099$

$\frac{1}{2\pi} = 0.1591549$

$\pi^2 = 9.869605$

$\pi^3 = 31.00628$

$\frac{1}{\pi^2} = 0.1013212$

$\frac{1}{\pi^3} = 0.03225153$

$\sqrt{\pi} = 1.772454$

$\frac{1}{\sqrt{\pi}} = 0.5641896$

$\sqrt{\frac{\pi}{2}} = 1.253314$

$\log \pi = 0.4971499$

$\log \pi^2 = 0.9942997$

$\log \sqrt{\pi} = 0.2485749$

$\log \frac{\pi}{2} = 0.1961199$

$\sqrt{2} = 1.414214$

$\sqrt{3} = 1.732051$

$\frac{1}{\sqrt{2}} = 0.7071068$

$\frac{1}{\sqrt{3}} = 0.5773503$

Mathematical Symbols

Figure 2-2. Mathematical Symbols

$+$	positive, plus, add
$-$	negative, minus, subtract
$\times$	times,multiply
$*$	multiply (computer use)
$\div$	divide, divided by
$/$	divide, divided by
$=$	equals
$\neq$	does not equal
$< >$	does not equal (computer use)
$<$	less than
$>$	greater than
$\leq$	less than or equal to
$<=$	less than or equal to (computer use)
$\geq$	greater than or equal to
$>=$	greater than or equal to (computer use)
$\simeq$	approximately equal to
$<<$	much less than
$>>$	much greater than
$\pm$	plus or minus
$\equiv$	identical with
$\therefore$	therefore
$\perp$	perpendicular to
$\parallel$	parallel to
$\angle$	angle
$\vert n \vert$	absolute value of n
$\sqrt{}$	square root
$\sqrt[n]{}$	nth root
$\cup, \vee, +$	union, disjunction, or
$\cap, \wedge, \bullet$	intersection, conjunction, and
$\sim$	not
Σ	sum

Fractional Inch, Decimal Inch, and Millimeters

Table 2-1 shows the equivalent fractions of an inch, decimal inches, and equivalent millimeters in 1/64th inch units.

	Fractions of an inch	Decimal Inch	Millimeters
1/64		0.0156	0.397
2/64	1/32	0.0313	0.794
3/64		0.0469	1.191
4/64	2/32 1/16	0.0625	1.588
5/64		0.0781	1.984
6/64	3/32	0.0938	2.381
7/64		0.1094	2.778
8/64	4/32 2/16 1/8	0.1250	3.175
9/64		0.1406	3.572
10/64	5/32	0.1563	3.969
11/64		0.1719	4.366
12/64	6/32 3/16	0.1875	4.763
13/64		0.2031	5.159
14/64	7/32	0.2188	5.556
15/64		0.2344	5.953
16/64	8/32 4/16 2/8 1/4	0.2500	6.350
17/64		0.2656	6.747
18/64	9/32	0.2813	7.144
19/64		0.2969	7.541
20/64	10/32 5/16	0.3125	7.938
21/64		0.3281	8.334
22/64	11/32	0.3438	8.731
23/64		0.3594	9.128
24/64	12/32 6/16 3/8	0.3750	9.525
25/64		0.3906	9.922
26/64	13/32	0.4063	10.319
27/64		0.4219	10.716
28/64	14/32 7/16	0.4375	11.113
29/64		0.4531	11.509
30/64	15/32	0.4688	11.906
31/64		0.4844	12.303
32/64	16/32 8/16 4/8 2/4 1/2	0.5000	12.700
33/64		0.5156	13.097
34/64	17/32	0.5313	13.494
35/64		0.5469	13.891
36/64	18/32 9/16	0.5625	14.288
37/64		0.5781	14.684
38/64	19/32	0.5938	15.081
39/64		0.6094	15.478
40/64	20/32 10/16 5/8	0.6250	15.875

41/64						0.6406	16.272
42/64	21/32					0.6563	16.669
43/64						0.6719	17.066
44/64	22/32	11/16				0.6875	17.463
45/64						0.7031	17.859
46/64	23/32					0.7188	18.256
47/64						0.7344	18.653
48/64	24/32	12/16	6/8	3/4		0.7500	19.050
49/64						0.7656	19.447
50/64	25/32					0.7813	19.844
51/64						0.7969	20.241
52/64	26/32	13/16				0.8125	20.637
53/64						0.8281	21.034
54/64	27/32					0.8438	21.431
55/64						0.8594	21.828
56/64	28/32	14/16	7/8			0.8750	22.225
57/64						0.8906	22.622
58/64	29/32					0.9063	23.019
59/64						0.9219	23.416
60/64	30/32	15/16				0.9375	23.813
61/64						0.9531	24.209
62/64	31/32					0.9688	24.606
63/64						0.9844	25.003
64/64	32/32	16/16	8/8	4/4	2/2	1.0000	25.400

Table 2-1. Fractional Inch, Decimal Inch, and Millimeters

Powers of Ten and Scientific Notation.

Very large and very small numbers can be written as powers of ten. For example, 1,234,000 can also be written as 1.234×10^6, and 0.000456 can also be written as 4.56 10^{-4}. This method of writing numbers is called scientific notation. Powers of ten from a millionth part to one million are as follows:

$.000001 = 10^{-6}$
$.00001 = 10^{-5}$
$.0001 = 10^{-4}$
$.001 = 10^{-3}$
$.01 = 10^{-2}$
$.1 = 10^{-1}$
$1 = 10^0$
$10 = 10^1$
$100 = 10^2$
$1000 = 10^3$

Note: Any number to the 0 power is 1

$10000 = 10^4$
$100000 = 10^5$
$1000000 = 10^6$

This concept can be extended to any size of number large or small. To change any number to scientific notation, move the decimal point until the number is in the form X.XXX. As you move the decimal point, adjust the power of ten by adding one if the decimal point is moved to the left or by subtracting one if the decimal point is moved to the right.

Example: Change 1,978,524 to scientific notation

1978524×10^0 original number
197852.4×10^1
19785.24×10^2
1978.524×10^3
197.8524×10^4
19.78524×10^5
1.978524×10^6

Example: Change 0.000678 to scientific notation

0.000678×10^0 original number
0.00678×10^{-1}
0.0678×10^{-2}
0.678×10^{-3}
6.78×10^{-4}

Adding and Subtracting Numbers in Scientific Notation.

To add or subtract numbers in scientific notation, change one of the numbers so that both powers of ten are equal and then add.

Example: Add 6.789×10^3 and 9.76×10^1

Adjust 6.789×10^3:

67.89×10^2
678.9×10^1

Add:

$$\begin{array}{r} 9.76 \times 10^1 \\ \underline{678.9 \times 10^1} \\ 688.66 \times 10^1 \end{array} = 6886.6$$

Multiplying Numbers in Scientific Notation

To multiply numbers in scientific notation, multiply the mixed numbers and add the exponents, for a new power of ten.

Example: Multiply 0.0000345 x 123,560

These numbers are 3.45×10^{-5} and 1.2356×10^{5} in scientific notation. Multiplying 3.45 times 1.2356 gives:

$3.45 \times 1.2356 = 4.262$

Adding the exponents gives:

$-5 + 5 = 0$

The result is therefore 4.262×10^{0} or 4.262

Dividing Numbers in Scientific Notation.

To divide numbers in scientific notation, divide the mixed numbers and subtract the exponents, for a new power of ten.

Example: Divide 123,560 by 0.0000345

These numbers are 1.2356×10^{5} and 3.45×10^{-5} in scientific notation. Dividing 1.2356 by 3.45 gives:

$1.2356 / 3.45 = 0.358$

Subtracting -5 from 5 gives

$5 - (-5) = 5 + 5 = 10$

The result is therefore 0.358×10^{10} or
3,580,000,000

Finding the Reciprocal of a Number

To find the reciprocal of a number in scientific notation (1 divided by the number), change the sign of the power of ten and divide the mixed number into 1.

Example: Find the reciprocal of 1.2356×10^{-5}

$$\frac{1}{1.2356 \times 10^{-5}} = 1/1.2356 \times 10^{5} = 0.8093 \times 10^{5} =$$

$$= 80{,}930$$

Powers

To find the power of a number in scientific notation, multiply the mixed number times itself the number of times equal to the power and multiply the power of ten times the power.

Example: Find the square of 1.2356×10^5

$1.2356 \times 1.2356 = 1.5267$

$2 * 5 = 10$

The square is therefore 1.52676×10^{10} or

15,267,000,000

Example: Find the cube of 1.2356×10^2

$1.2356 \times 1.2356 \times 1.2356 = 1.8864$

$3 * 2 = 6$

The cube is therefore 1.8864×10^6 or 1,886,400

Example: Find the square root of 1.2356×10^5

First convert to an even power of ten so that the resulting power of ten is not fractional.

$1.2356 \times 10^5 = 12.356 \times 10^4$

The square root of a number is the 1/2 power (cube root is 1/3 power, 4th root is 1/4 power, etc.) Find the square root of 12.356.

square root of $12.356 = 3.515$

$4 / 2 = 2$

The square root is therefore 3.515×10^2 or 351.5.

Mixed Operations Using Scientific Notation

The above operations can be carried out for combinations of addition, subtraction, multiplication, division, and powers by working with one operation at a time, as shown in Figure 2-3.

Original:

$$\frac{(123{,}876 \times 0.05 \times 13)^2}{17.56 \times 3}$$

Step 1:

$$\frac{(1.23876 \times 10^5 \times 5 \times 10^{-2} \times 1.3 \times 10^1)^2}{1.756 \times 10^1 \times 3 \times 10^0}$$

Steps 2,3:

$$1.23876 \times 5 = 6.1938 \times 10^3$$

$$\frac{(\overbrace{1.23876 \times 10^5 \times 5 \times 10^{-2}} \times 1.3 \times 10^1)^2}{\underbrace{1.756 \times 10^1 \times 3 \times 10^0}_{5.268 \times 10^1}}$$

Step 4:

$$6.1938 \times 1.3 = 8.05194 \times 10^4$$

$$\frac{(\overbrace{6.1938 \times 10^3 \qquad \times 1.3 \times 10^1})^2}{5.268 \times 10^1}$$

Step 5:

$$64.834 \times 10^{16}$$

$$\frac{\overbrace{(8.05194 \times 10^4)^2}}{5.268 \times 10^1}$$

Step 6:

$$\frac{64.834 \times 10^8}{5.268 \times 10^1} = 12.3 \times 10^7$$

$$= 123{,}000{,}000$$

Figure 2-3. Mixed Operations in Scientific Notation

Logarithms

A logarithm is the power to which a number must be raised to produce a given number. The logarithm to the base 10 of 1012, for example, is 3.0043, as 10 must be raised to the 3.0043 power to produce 1012. Logarithms are useful in multiplication, division, powers, and roots of numbers.

Any number may be used as the base for logarithmic operations - 2, 4, 7, 10, etc. The two common bases for logarithms, however, are base 10 (common logarithms) and base e (Napierian logarithms, using a base of e=2.7182 . . .).

Logarithms are written in the form C.MMMMM, where C is the characteristic of the logarithm and M..M is the "mantissa" of the logarithm. The characteristic of the logarithm represents the whole number power to which the number is raised. The mantissa represents the fractional part of the power. The characteristic for common logs can be found by the maximum power of 10 represented by the number.

Examples: 7,456 has a characteristic of 3, as the 7 represents 10 to the third power. 601,467 has a characteristic of 5, as the 6 represents 10 to the fifth power. 0.007 has a characteristic of -3, as the 7 represents 10 to the -3 power.

Table 2-2 shows common logarithms for three-digit numbers. To find the logarithm of a number, find the first two digits of the number in the left hand column and the third digit in one of the ten rows across the top. The value found will be the mantissa of the number. The complete logarithm of the number will be the characteristic and mantissa grouped together to make a logarithm of the form C.MMM.

Table 2-2. Common Logarithms

N	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6159	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981

Table 2-2. Common Logarithms (Cont.)

N	0	1	2	3	4	5	6	7	8	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680

Table 2-2. Common Logarithms (Cont.)

N	0	1	2	3	4	5	6	7	8	9
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

Example: Find the common logarithm of 5578. Find the 55 digits in the first column, and the 7 digit in the seventh row. The mantissa will be .7459. Combined with the characteristic of 3, the common logarithm is 3.7459. (10 to the 3.7459 power is 5578.

The antilogarithm is the number corresponding to a given logarithm. The antilogarithm for a common logarithm is the result of 10 raised to the power given by the log value. To find the antilogarithm, find the value in the table closest to the mantissa value. Adjust the decimal point based upon the value of the characteristic.

Example: Find the antilogarithm of 2.789. Scanning the table for the closest value to 789, we find the corresponding digits of 61 5. If the characteristic had been 0, the antilogarithm would have been 6.15. However, the characteristic is 2, so the decimal point is moved two places to the right — 615. (10 to the 2.789 power is 615.)

Numbers expressed as logarithmic values can be processed and the results reconverted to the actual value.

To multiply two numbers by logarithms, add the logs and reconvert.

Example: 2340 x 1234:

log of 2340 = 3.369
log of 1234 = 3.091

sum = 6.460 antilog = 2884000 (2340 x 1234)

To divide two numbers by logarithms, subtract the logs and reconvert.

Example: 2340 / 99.0:

log of 2340 = 3.369 log of 99.0 = 1.995

difference = 1.374 antilog = 23.65 (2340 / 99.0)

To raise a number to any power, multiply the logarithm by the power and reconvert.

Example: $27.7^{3.78}$:

log of 27.7 = 1.442 x 3.78 = 5.45 antilog = 281800

To find the root of any number, divide the logarithm by the index of the root and reconvert.

Example: $\sqrt[3]{5610}$:

log of 5610 = 3.748 / 3 = 1.25 antilog = 17.8

Algebraic Operations

If $A + B = C$, then:

$A = C - B$
$B = C - A$
$A + B - C = 0$

if $A = B/C$, then:

$B = AC$
$C = B/A$

If $\frac{A}{B} = \frac{C}{D}$, then:

$A = BC/D$
$B = AD/C$
$C = AD/B$
$D = CB/A$

Powers and Roots

Any number to the 0 power equals 1 if the number is not equal to 0:

Example:

$10^0 = 1$

A number to a negative power equals the reciprocal of the number to that power:

Example:

$4^{-3} = 1/4^3 = 1/64$

A number to a fractional power equals the number raised to the power of the numerators with the root of the denominator then taken.

Examples:

$16^{1/2} = \sqrt{16} = 4$ (square root of 16)

$27^{1/3} = \sqrt[3]{27} = 3$ (cube root of 27)

$4^{3/2} = \sqrt{64} = 8$ (4 to the third power is 64, square root of 64 is 8)

$11^{5/3} = \sqrt[3]{161051} = 54.4$ (11 to the fifth power is 161051, cube root of 161051 is 54.4 . . .)

The product of two numbers having the same base number but raised to different powers is equal to the base number raised to the sum of the two powers.

$a^x \text{ x } a^y = a^{(x+y)}$

Example:

$3^3 \text{ x } 3^2 = 27 \text{ x } 9 = 243 =$

$3^{(3+2)} = 3^5 = 243$

The quotient of two numbers having the same base number but raised to different powers is equal to the base number raised to the difference of the powers.

$$\frac{a^x}{a^y} = a^{(x-y)}$$

Example:

$$\frac{3^5}{3^3} = \frac{243}{27} = 9 =$$

$3^{(5-3)} = 3^2 = 9$

The power of a power of a base number equals the base number raised to the quotient of the two powers:

$(a^x)^y = a^{xy}$

Example:

$(3^3)^2 = 27^2 = 729 =$

$3^{(3 \text{ x } 2)} = 3^6 = 729$

The power of a fraction is equal to the power of the numerator raised to the power divided by the denominator raised to the power.

$$\frac{a^x}{b} = \frac{a^x}{b^x}$$

Example:

$$\frac{2^3}{3} = \frac{2}{3} \text{ x } \frac{2}{3} \text{ x } \frac{2}{3} = \frac{8}{27} =$$

$$\frac{2^3}{3^3} = \frac{8}{27}$$

The power of a product is equal to the product of the individual factors.
$(ab)^x = a^x \text{ x } b^x$

Example:

$(3 \text{ x } 5)^3 = 15^3 = 3375 =$

$3^3 \text{ x } 5^3 = 27 \text{ x } 125 = 3375$

The root of a product is equal to the roots of the individual factors.

$$\sqrt{xy} = \sqrt{x} \text{ x } \sqrt{y}$$

Example:

$$\sqrt{41 \text{ x } 3} = \sqrt{123} = 11.0$$

$$\sqrt{41} \text{ x } \sqrt{3} = 6.4 \text{ x } 1.73 = 11.0$$

Quadratic Equations

Quadratic equations can be reduced to the form

$$ax^2 + bx + c = 0$$

The roots of the equation can then be found by

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

No, one, or two real roots may exist.

Geometric Formulas for Area and Volume

Figure 2-4 shows common geometric shapes and gives formulas for area and volume. In the figure A stands for Area and V for volume.

General Triangle (right,equilateral, other)

$$A = \frac{bh}{2}$$

Square

$$A = b^2$$

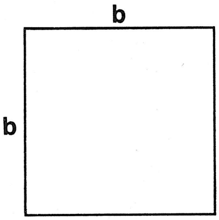
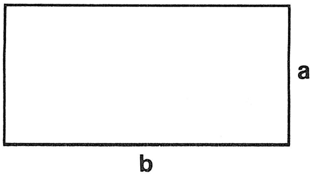


Figure 2-4. Area and Volume Formulas

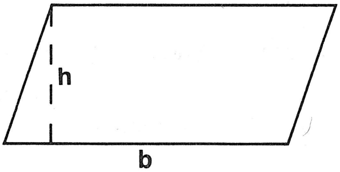
Rectangle

$A = ab$



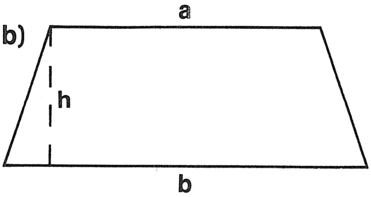
Parallelogram

$A = bh$



Trapezoid

$A = \frac{h}{2}(a+b)$



Polygons

$A = KS^2$ where k depends upon the number of sides, as follows:

# of sides	k	figure
5	1.7205	pentagon
6	2.5981	hexagon
7	3.6334	hetagon
8	4.8284	octagon
9	6.1818	nonagon
10	7.6942	decagon
11	9.3656	undecagon
12	11.1962	dodecagon

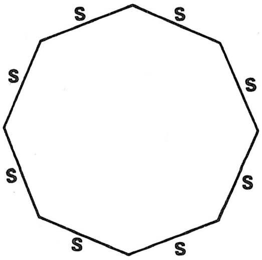


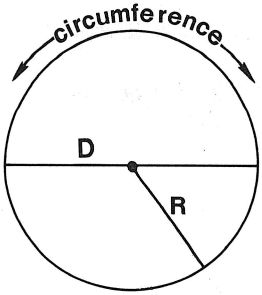
Figure 2-4. Area and Volume Formulas (Cont.)

Circle

circumference $= 2\pi R = \pi D$

$A = \pi r^2$

$\pi = 3.14159$

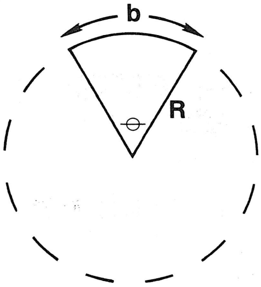


Sector of a Circle

$$A = \frac{bR}{2} \pi R^2 \left(\frac{\theta}{360}\right)$$

θ in degrees

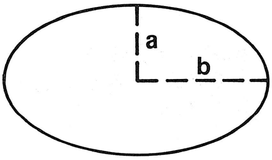
$\pi = 3.14159$



Ellipse

$A = \pi ab$

$\pi = 3.14159$



Cube

$A = 6b^2$

$V = b^3$

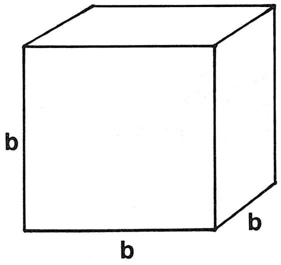
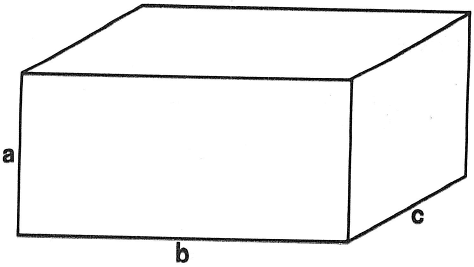


Figure 2-4. Area and Volume Formulas (Cont.)

Rectangular Box (Parallepiped)

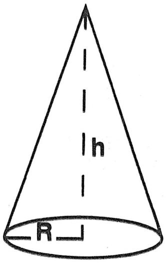
$A = 2\,(ab + bc + ca)$
$V = abc$



Cone

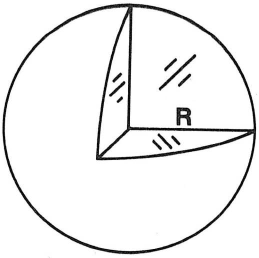
$A = \pi R \sqrt{R^2 + h^2}$
$V = \dfrac{\pi R^2 h}{3}$

$\pi = 3.14159$



Sphere

$A = \pi D^2 = 12.57\ R^2$
$V = 1/6\ \pi\ D^3 = 4.189\ R^3$
$\pi = 3.14159$



Cylinder

$A = 2\pi R(R + h)$
$V = \pi R^2 h$
$\pi = 3.14159$

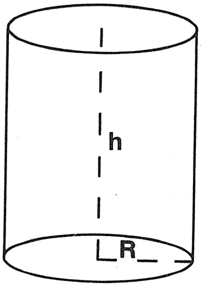


Figure 2-4. Area and Volume Formulas (Cont.)

Trigonometric Formulas

Figure 2-5 shows the common trigonometric identities for a right triangle. Formulas are also given for finding the remaining angle and sides, given one angle and one side, and for finding the remaining side and angles, given two sides.

$\sin A = a/c$

$\cos A = b/c$

$\tan A = a/b$

$\csc A = c/a$ $(1/\sin A)$

$\sec A = c/b$ $(1/\cos A)$

$\cot A = b/a$ $(1/\tan A)$

$\sin B = b/c$

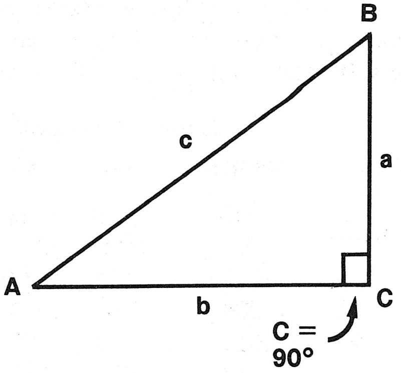
$\cos B = a/c$

$\tan B = b/b$

$\csc B = c/b$ $(1/\sin B)$

$\sec B = c/a$ $(1/\cos B)$

$\cot B = a/b$ $(1/\tan B)$



Given A and a:

$B = 90 - A$ $b = a \cot A$ $c = a \csc A$

Given A and b:

$B = 90 - A$ $a = b \tan A$ $c = a \sec A$

Given A and c:

$B = 90 - A$ $a = c \csc A$ $b = c \cos A$

Given B and a:

$A = 90 - B$ $b = a \tan B$ $c = a \sec B$

Given B and b:

$A = 90 - B$ $a = b \cot B$ $c = a \csc B$

Given B and c:

$A = 90 - B$ $a = c \cos B$ $b = c \sin B$

Given a and b:

$A = \arctan a/b$ $B = 90 - A$ $c = \sqrt{a^2 + b^2}$

Given a and c:

$A = \arcsin a/c$ $B = 90 - A$ $b = c \cos A$

Given b and c:

$A = \arccos b/c$ $B = 90 - A$ $a = c \csc A$

Figure 2-5. Trigonometric Formulas

Trigonometric Values

Table 2-3 provides values for sines, cosines, tangents, and cotangents of angles from 0 degrees to 45 degrees in increments of 10 minutes (1/6 degree increments). The table is read from beginning to end for angles of 0 through 45 degrees and in reverse for angles of 45 through 90 degrees. The left hand degree and radians columns (0 to 45 degrees) are used with the heading at the top of each page and the right hand degree and radians columns (90 to 45 degrees) are used with the heading at the bottom of each page. For example, the cosine of 6 degrees 10 minutes is .9942, while the cotangent of 88 degrees 30 minutes is .0495. Note that the secant function is the inverse of the cosine function and that the cosecant function is the inverse of the sine function. The secant of 6 degrees, 10 minutes is therefore 1/.9942 or 1.006.

Table 2-3. Natural Trigonometric Function

Degrees		Radians	Sin	Cos	Tan	Cot			
0°	0'	.0000	.0000	1.0000	.0000	infinite	1.5708	90°	0'
	10	.0029	.0029	1.0000	.0029	343.8	1.5679		50
	20	.0058	.0058	1.0000	.0058	171.9	1.5650		40
	30	.0087	.0087	1.0000	.0087	114.6	1.5621		30
	40	.0116	.0116	.9999	.0116	85.94	1.5592		20
	50	.0145	.0145	.9999	.0145	68.75	1.5563		10
1°	0'	.0175	.0175	.9998	.0175	57.29	1.5533	89°	0'
	10	.0204	.0204	.9998	.0204	49.10	1.5504		50
	20	.0233	.0233	.9997	.0233	42.96	1.5475		40
	30	.0262	.0262	.9997	.0262	38.19	1.5446		30
	40	.0291	.0291	.9996	.0291	34.37	1.5417		20
	50	.0320	.0320	.9995	.0320	31.24	1.5388		10
2°	0'	.0349	.0349	.9994	.0349	28.64	1.5359	88°	0'
	10	.0378	.0378	.9993	.0378	26.43	1.5330		50
	20	.0407	.0407	.9992	.0407	24.54	1.5301		40
	30	.0436	.0436	.9990	.0437	22.90	1.5272		30
	40	.0465	.0465	.9989	.0466	21.47	1.5243		20
	50	.0495	.0494	.9988	.0495	20.21	1.5213		10
3°	0'	.0524	.0523	.9986	.0524	19.08	1.5184	87°	0'
	10	.0553	.0552	.9985	.0553	18.07	1.5155		50
	20	.0582	.0581	.9983	.0582	17.17	1.5126		40
	30	.0611	.0610	.9981	.0612	16.35	1.5097		30
	40	.0640	.0640	.9980	.0641	15.60	1.5068		20
	50	.0669	.0669	.9978	.0670	14.92	1.5039		10
4°	0'	.0698	.0698	.9976	.0699	14.30	1.5010	86°	0'
	10	.0727	.0727	.9974	.0729	13.73	1.4981		50
	20	.0756	.0756	.9971	.0758	13.20	1.4952		40
	30	.0785	.0785	.9969	.0787	12.71	1.4923		30
	40	.0814	.0814	.9967	.0816	12.25	1.4894		20
	50	.0844	.0843	.9964	.0846	11.83	1.4864		10
			Cos	Sin	Cot	Tan	Radians	Degrees	

Table 2-3. Natural Trigonometric Function (Cont.)

Degrees		Radians	Sin	Cos	Tan	Cot			
5°	0'	.0873	.0872	.9962	.0875	11.43	1.4835	85°	0'
	10	.0902	.0901	.9959	.0904	11.06	1.4806		50
	20	.0931	.0929	.9957	.0934	10.71	1.4777		40
	30	.0960	.0958	.9954	.0963	10.39	1.4748		30
	40	.0989	.0987	.9951	.0992	10.08	1.4719		20
	50	.1018	.1016	.9948	.1022	9.788	1.4690		10
6°	0'	.1047	.1045	.9945	.1051	9.514	1.4661	84°	0'
	10	.1076	.1074	.9942	.1080	9.255	1.4632		50
	20	.1105	.1103	.9939	.1110	9.010	1.4603		40
	30	.1134	.1132	.9936	.1139	8.777	1.4574		30
	40	.1164	.1161	.9932	.1169	8.556	1.4544		20
	50	.1193	.1190	.9929	.1198	8.345	1.4515		10
7°	0'	.1222	.1219	.9925	.1228	8.144	1.4486	83°	0'
	10	.1251	.1248	.9922	.1257	7.953	1.4457		50
	20	.1280	.1276	.9918	.1287	7.770	1.4428		40
	30	.1309	.1305	.9914	.1317	7.596	1.4399		30
	40	.1338	.1334	.9911	.1346	7.429	1.4370		20
	50	.1367	.1363	.9907	.1376	7.269	1.4341		10
8°	0'	.1396	.1392	.9903	.1405	7.115	1.4312	82°	0'
	10	.1425	.1421	.9899	.1435	6.968	1.4283		50
	20	.1454	.1449	.9894	.1465	6.827	1.4254		40
	30	.1484	.1478	.9890	.1495	6.691	1.4224		30
	40	.1513	.1507	.9886	.1524	6.561	1.4195		20
	50	.1542	.1536	.9881	.1554	6.435	1.4166		10
9°	0'	.1571	.1564	.9877	.1584	6.314	1.4137	81°	0'
	10	.1600	.1593	.9872	.1614	6.197	1.4108		50
	20	.1629	.1622	.9868	.1644	6.084	1.4079		40
	30	.1658	.1650	.9863	.1673	5.976	1.4050		30
	40	.1687	.1679	.9858	.1703	5.871	1.4021		20
	50	.1716	.1708	.9853	.1733	5.769	1.3992		10
10°	0'	.1745	.1736	.9848	.1763	5.671	1.3963	80°	0'
	10	.1774	.1765	.9843	.1793	5.576	1.3934		50
	20	.1804	.1794	.9838	.1823	5.485	1.3904		40
	30	.1833	.1822	.9833	.1853	5.396	1.3875		30
	40	.1862	.1851	.9827	.1883	5.309	1.3846		20
	50	.1891	.1880	.9822	.1914	5.226	1.3817		10
11°	0'	.1920	.1908	.9816	.1944	5.145	1.3788	79°	0'
	10	.1949	.1937	.9811	.1974	5.066	1.3759		50
	20	.1978	.1965	.9805	.2004	4.989	1.3730		40
	30	.2007	.1994	.9799	.2035	4.915	1.3701		30
	40	.2036	.2022	.9793	.2065	4.843	1.3672		20
	50	.2065	.2051	.9787	.2095	4.773	1.3643		10
			Cos	Sin	Cot	Tan	Radians	Degrees	

Table 2-3. Natural Trigonometric Function (Cont.)

Degrees		Radians	Sin	Cos	Tan	Cot			
12°	0'	.2094	.2079	.9781	.2126	4.705	1.3614	78°	0'
	10	.2123	.2108	.9775	.2156	4.638	1.3585		50
	20	.2153	.2136	.9769	.2186	4.574	1.3555		40
	30	.2182	.2164	.9763	.2217	4.511	1.3526		30
	40	.2211	.2193	.9757	.2247	4.449	1.3497		20
	50	.2240	.2221	.9750	.2278	4.390	1.3468		10
13°	0'	.2269	.2250	.9744	.2309	4.331	1.3439	77°	0'
	10	.2298	.2278	.9737	.2339	4.275	1.3410		50
	20	.2327	.2306	.9730	.2370	4.219	1.3381		40
	30	.2356	.2334	.9724	.2401	4.165	1.3352		30
	40	.2385	.2363	.9717	.2432	4.113	1.3323		20
	50	.2414	.2391	.9710	.2462	4.061	1.3294		10
14°	0'	.2443	.2419	.9703	.2493	4.011	1.3265	76°	0'
	10	.2473	.2447	.9696	.2524	3.962	1.3235		50
	20	.2502	.2476	.9689	.2555	3.914	1.3206		40
	30	.2531	.2504	.9681	.2586	3.867	1.3177		30
	40	.2560	.2532	.9674	.2617	3.821	1.3148		20
	50	.2589	.2560	.9667	.2648	3.776	1.3119		10
15°	0'	.2618	.2588	.9659	.2679	3.732	1.3090	75°	0'
	10	.2647	.2616	.9652	.2711	3.689	1.3061		50
	20	.2676	.2644	.9644	.2742	3.647	1.3032		40
	30	.2705	.2672	.9636	.2773	3.606	1.3003		30
	40	.2734	.2700	.9628	.2805	3.566	1.2974		20
	50	.2763	.2728	.9621	.2836	3.526	1.2945		10
16°	0'	.2793	.2756	.9613	.2867	3.487	1.2915	74°	0'
	10	.2822	.2784	.9605	.2899	3.450	1.2886		50
	20	.2851	.2812	.9596	.2931	3.412	1.2857		40
	30	.2880	.2840	.9588	.2962	3.376	1.2828		30
	40	.2909	.2868	.9580	.2994	3.340	1.2799		20
	50	.2938	.2896	.9572	.3026	3.305	1.2770		10
17°	0'	.2967	.2924	.9563	.3057	3.271	1.2741	73°	0'
	10	.2996	.2952	.9555	.3089	3.237	1.2712		50
	20	.3025	.2979	.9546	.3121	3.204	1.2683		40
	30	.3054	.3007	.9537	.3153	3.172	1.2654		30
	40	.3083	.3035	.9528	.3185	3.140	1.2625		20
	50	.3113	.3062	.9520	.3217	3.108	1.2595		10
18°	0'	.3142	.3090	.9511	.3249	3.078	1.2566	72°	0'
	10	.3171	.3118	.9502	.3281	3.047	1.2537		50
	20	.3200	.3145	.9492	.3314	3.018	1.2508		40
	30	.3229	.3173	.9483	.3346	2.989	1.2479		30
	40	.3258	.3201	.9474	.3378	2.960	1.2450		20
	50	.3287	.3228	.9465	.3411	2.932	1.2421		10
			Cos	Sin	Cot	Tan	Radians	Degrees	

Table 2-3. Natural Trigonometric Function (Cont.)

Degrees		Radians	Sin	Cos	Tan	Cot			
19°	0'	.3316	.3256	.9455	.3443	2.904	1.2392	71°	0'
	10	.3345	.3283	.9446	.3476	2.877	1.2363		50
	20	.3374	.3311	.9436	.3508	2.850	1.2334		40
	30	.3403	.3338	.9426	.3541	2.824	1.2305		30
	40	.3432	.3365	.9417	.3574	2.798	1.2276		20
	50	.3462	.3393	.9407	.3607	2.773	1.2246		10
20°	0'	.3491	.3420	.9397	.3640	2.747	1.2217	70°	0'
	10	.3520	.3448	.9387	.3673	2.723	1.2188		50
	20	.3549	.3475	.9377	.3706	2.699	1.2159		40
	30	.3578	.3502	.9367	.3739	2.675	1.2130		30
	40	.3607	.3529	.9356	.3772	2.651	1.2101		20
	50	.3636	.3557	.9346	.3805	2.628	1.2072		10
21°	0'	.3665	.3584	.9336	.3839	2.605	1.2043	69°	0'
	10	.3694	.3611	.9325	.3872	2.583	1.2014		50
	20	.3723	.3638	.9315	.3906	2.560	1.1985		40
	30	.3752	.3665	.9304	.3939	2.539	1.1956		30
	40	.3782	.3692	.9293	.3973	2.517	1.1926		20
	50	.3811	.3719	.9283	.4006	2.496	1.1897		10
22°	0'	.3840	.3746	.9272	.4040	2.475	1.1868	68°	0'
	10	.3869	.3773	.9261	.4074	2.455	1.1839		50
	20	.3898	.3800	.9250	.4108	2.434	1.1810		40
	30	.3927	.3827	.9239	.4142	2.414	1.1781		30
	40	.3956	.3854	.9228	.4176	2.394	1.1752		20
	50	.3985	.3881	.9216	.4210	2.375	1.1723		10
23°	0'	.4014	.3907	.9205	.4245	2.356	1.1694	67°	0'
	10	.4043	.3934	.9194	.4279	2.337	1.1665		50
	20	.4072	.3961	.9182	.4314	2.318	1.1636		40
	30	.4102	.3987	.9171	.4348	2.300	1.1606		30
	40	.4131	.4014	.9159	.4383	2.282	1.1577		20
	50	.4160	.4041	.9147	.4417	2.264	1.1548		10
24°	0'	.4189	.4067	.9135	.4452	2.246	1.1519	66°	0'
	10	.4218	.4094	.9124	.4487	2.229	1.1490		50
	20	.4247	.4120	.9112	.4522	2.211	1.1461		40
	30	.4276	.4147	.9100	.4557	2.194	1.1432		30
	40	.4305	.4173	.9088	.4592	2.177	1.1403		20
	50	.4334	.4200	.9075	.4628	2.161	1.1374		10
25°	0'	.4363	.4226	.9063	.4663	2.145	1.1345	65°	0'
	10	.4392	.4253	.9051	.4699	2.128	1.1316		50
	20	.4422	.4279	.9038	.4734	2.112	1.1286		40
	30	.4451	.4305	.9026	.4770	2.097	1.1257		30
	40	.4480	.4331	.9013	.4806	2.081	1.1228		20
	50	.4509	.4358	.9001	.4841	2.066	1.1199		10
			Cos	Sin	Cot	Tan	Radians	Degrees	

Table 2-3. Natural Trigonometric Function (Cont.)

Degrees		Radians	Sin	Cos	Tan	Cot			
26°	0'	.4538	.4384	.8988	.4877	2.050	1.1170	64°	0'
	10	.4567	.4410	.8975	.4913	2.035	1.1141		50
	20	.4596	.4436	.8962	.4950	2.020	1.1112		40
	30	.4625	.4462	.8949	.4986	2.006	1.1083		30
	40	.4654	.4488	.8936	.5022	1.991	1.1054		20
	50	.4683	.4514	.8923	.5059	1.977	1.1025		10
27°	0'	.4712	.4540	.8910	.5095	1.963	1.0996	63°	0'
	10	.4741	.4566	.8897	.5132	1.949	1.0967		50
	20	.4771	.4592	.8884	.5169	1.935	1.0937		40
	30	.4800	.4617	.8870	.5206	1.921	1.0908		30
	40	.4829	.4643	.8857	.5243	1.907	1.0879		20
	50	.4858	.4669	.8843	.5280	1.894	1.0850		10
28°	0'	.4887	.4695	.8829	.5317	1.881	1.0821	62°	0'
	10	.4916	.4720	.8816	.5354	1.868	1.0792		50
	20	.4945	.4746	.8802	.5392	1.855	1.0763		40
	30	.4974	.4772	.8788	.5430	1.842	1.0734		30
	40	.5003	.4797	.8774	.5467	1.829	1.0705		20
	50	.5032	.4823	.8760	.5505	1.816	1.0676		10
29°	0'	.5061	.4848	.8746	.5543	1.804	1.0647	61°	0'
	10	.5091	.4874	.8732	.5581	1.792	1.0617		50
	20	.5120	.4899	.8718	.5619	1.780	1.0588		40
	30	.5149	.4924	.8704	.5658	1.767	1.0559		30
	40	.5178	.4950	.8689	.5696	1.756	1.0530		20
	50	.5207	.4975	.8675	.5735	1.744	1.0501		10
30°	0'	.5236	.5000	.8660	.5774	1.732	1.0472	60°	0'
	10	.5265	.5025	.8646	.5812	1.720	1.0443		50
	20	.5294	.5050	.8631	.5851	1.709	1.0414		40
	30	.5323	.5075	.8616	.5890	1.698	1.0385		30
	40	.5352	.5100	.8601	.5930	1.686	1.0356		20
	50	.5381	.5125	.8587	.5969	1.675	1.0327		10
31°	0'	.5411	.5150	.8572	.6009	1.664	1.0297	59°	0'
	10	.5440	.5175	.8557	.6048	1.653	1.0268		50
	20	.5469	.5200	.8542	.6088	1.643	1.0239		40
	30	.5498	.5225	.8526	.6128	1.632	1.0210		30
	40	.5527	.5250	.8511	.6168	1.621	1.0181		20
	50	.5556	.5275	.8496	.6208	1.611	1.0152		10
32°	0'	.5585	.5299	.8480	.6249	1.600	1.0123	58°	0'
	10	.5614	.5324	.8465	.6289	1.590	1.0094		50
	20	.5643	.5348	.8450	.6330	1.580	1.0065		40
	30	.5672	.5373	.8434	.6371	1.570	1.0036		30
	40	.5701	.5398	.8418	.6412	1.560	1.0007		20
	50	.5730	.5422	.8403	.6453	1.550	0.9978		10
			Cos	Sin	Cot	Tan	Radians	Degrees	

Table 2-3. Natural Trigonometric Function (Cont.)

Degrees		Radians	Sin	Cos	Tan	Cot			
33°	0'	.5760	.5446	.8387	.6494	1.540	0.9948	57°	0'
	10	.5789	.5471	.8371	.6536	1.530	0.9919		50
	20	.5818	.5495	.8355	.6577	1.520	0.9890		40
	30	.5847	.5519	.8339	.6619	1.511	0.9861		30
	40	.5876	.5544	.8323	.6661	1.501	0.9832		20
	50	.5905	.5568	.8307	.6703	1.492	0.9803		10
34°	0'	.5934	.5592	.8290	.6745	1.483	0.9774	56°	0'
	10	.5963	.5616	.8274	.6787	1.473	0.9745		50
	20	.5992	.5640	.8258	.6830	1.464	0.9716		40
	30	.6021	.5664	.8241	.6873	1.455	0.9687		30
	40	.6050	.5688	.8225	.6916	1.446	0.9658		20
	50	.6080	.5712	.8208	.6959	1.437	0.9628		10
35°	0'	.6109	.5736	.8192	.7002	1.428	0.9599	55°	0'
	10	.6138	.5760	.8175	.7046	1.419	0.9570		50
	20	.6167	.5783	.8158	.7089	1.411	0.9541		40
	30	.6196	.5807	.8141	.7133	1.402	0.9512		30
	40	.6225	.5831	.8124	.7177	1.393	0.9483		20
	50	.6254	.5854	.8107	.7221	1.385	0.9454		10
36°	0'	.6283	.5878	.8090	.7265	1.376	0.9425	54°	0'
	10	.6312	.5901	.8073	.7310	1.368	0.9396		50
	20	.6341	.5925	.8056	.7355	1.360	0.9367		40
	30	.6370	.5948	.8039	.7400	1.351	0.9338		30
	40	.6400	.5972	.8021	.7445	1.343	0.9308		20
	50	.6429	.5995	.8004	.7490	1.335	0.9279		10
37°	0'	.6458	.6018	.7986	.7536	1.327	0.9250	53°	0'
	10	.6487	.6041	.7969	.7581	1.319	0.9221		50
	20	.6516	.6065	.7951	.7627	1.311	0.9192		40
	30	.6545	.6088	.7934	.7673	1.303	0.9163		30
	40	.6574	.6111	.7916	.7720	1.295	0.9134		20
	50	.6603	.6134	.7898	.7766	1.288	0.9105		10
38°	0'	.6632	.6157	.7880	.7813	1.280	0.9076	52°	0'
	10	.6661	.6180	.7862	.7860	1.272	0.9047		50
	20	.6690	.6202	.7844	.7907	1.265	0.9018		40
	30	.6720	.6225	.7826	.7954	1.257	0.8988		30
	40	.6749	.6248	.7808	.8002	1.250	0.8959		20
	50	.6778	.6271	.7790	.8050	1.242	0.8930		10
39°	0'	.6807	.6293	.7771	.8098	1.235	0.8901	51°	0'
	10	.6836	.6316	.7753	.8146	1.228	0.8872		50
	20	.6865	.6338	.7735	.8195	1.220	0.8843		40
	30	.6894	.6361	.7716	.8243	1.213	0.8814		30
	40	.6923	.6383	.7698	.8292	1.206	0.8785		20
	50	.6952	.6406	.7679	.8342	1.199	0.8756		10
			Cos	Sin	Cot	Tan	Radians	Degrees	

Table 2-3. Natural Trigonometric Function (Cont.)

Degrees		Radians	Sin	Cos	Tan	Cot			
40°	0'	.6981	.6428	.7660	.8391	1.192	0.8727	50°	0'
	10	.7010	.6450	.7642	.8441	1.185	0.8698		50
	20	.7039	.6472	.7623	.8491	1.178	0.8669		40
	30	.7069	.6494	.7604	.8541	1.171	0.8639		30
	40	.7098	.6517	.7585	.8591	1.164	0.8610		20
	50	.7127	.6539	.7566	.8642	1.157	0.8581		10
41°	0'	.7156	.6561	.7547	.8693	1.150	0.8552	49°	0'
	10	.7185	.6583	.7528	.8744	1.144	0.8523		50
	20	.7214	.6604	.7509	.8796	1.137	0.8494		40
	30	.7243	.6626	.7490	.8847	1.130	0.8465		30
	40	.7272	.6648	.7470	.8899	1.124	0.8436		20
	50	.7301	.6670	.7451	.8952	1.117	0.8407		10
42°	0'	.7330	.6691	.7431	.9004	1.111	0.8378	48°	0'
	10	.7359	.6713	.7412	.9057	1.104	0.8349		50
	20	.7389	.6734	.7392	.9110	1.098	0.8319		40
	30	.7418	.6756	.7373	.9163	1.091	0.8290		30
	40	.7447	.6777	.7353	.9217	1.085	0.8261		20
	50	.7476	.6799	.7333	.9271	1.079	0.8232		10
43°	0'	.7505	.6820	.7314	.9325	1.072	0.8203	47°	0'
	10	.7534	.6841	.7294	.9380	1.066	0.8174		50
	20	.7563	.6862	.7274	.9435	1.060	0.8145		40
	30	.7592	.6884	.7254	.9490	1.054	0.8116		30
	40	.7621	.6905	.7234	.9545	1.048	0.8087		20
	50	.7650	.6926	.7214	.9601	1.042	0.8058		10
44°	0'	.7679	.6947	.7193	.9657	1.036	0.8029	46°	0'
	10	.7709	.6967	.7173	.9713	1.030	0.7999		50
	20	.7738	.6988	.7153	.9770	1.024	0.7970		40
	30	.7767	.7009	.7133	.9827	1.018	0.7941		30
	40	.7796	.7030	.7112	.9884	1.012	0.7912		20
	50	.7825	.7050	.7092	.9942	1.006	0.7883		10
45°	0'	.7854	.7071	.7071	1.0000	1.000	0.7854	45°	0'
			Cos	Sin	Cot	Tan	Radians	Degrees	

Section 3
Audio Data

Audio Frequency Spectrum

The audio-frequency extends from about 15 to 20,000 hertz. Figure 3-1 shows the frequency range of sounds produced by musical and electronic devices. Most sounds contain a combination of frequencies dispersed over the range of the sound with varying amounts of loudness. The characteristics of the sound or instrument is determined by the fundamental frequency (such as A above middle C on the piano at 440 hertz) and harmonic frequencies, or multiples necessary to accurately reproduce the instrument or sound.

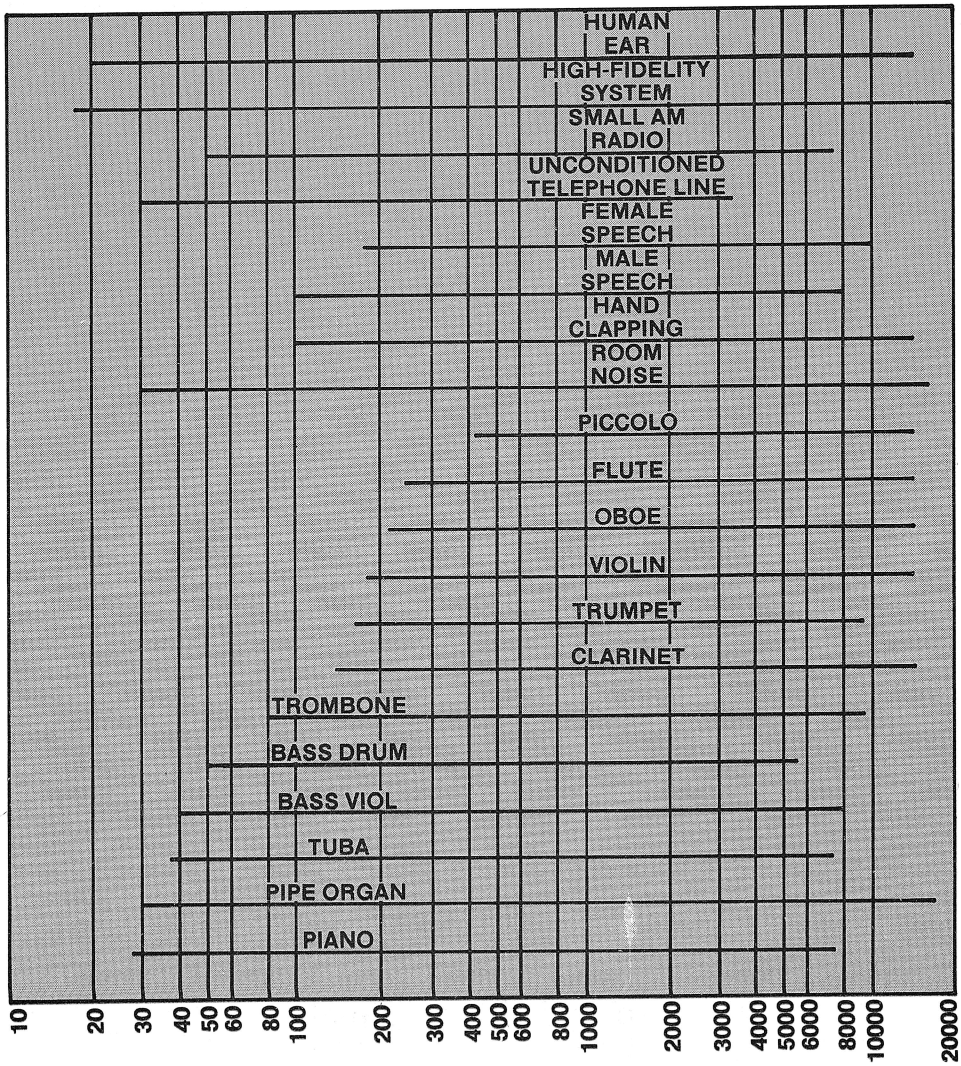


Figure 3-1. Sounds Vs. Frequencies

Musical Note Frequency Table

Table 3-1 shows ten octaves in the scale of equal temperament with the corresponding audio frequencies for the 12 notes per octave.

Table 3-1. Equal Temperament Musical Scale

Octave 1

Note	Frequency (Hertz)
C	16.352
C#-Db	17.324
D	18.354
D#-Eb	19.445
E	20.602
F	21.827
F#-Gb	23.125
G	24.500
G#-Ab	25.957
A	27.500
A#-Bb	29.135
B	30.868

Octave 2

Note	Frequency
C	32.703
C#-Db	34.648
D	36.708
D#-Eb	38.891
E	41.203
F	43.654
F#-Gb	46.249
G	48.999
G#-Ab	51.913
A	55.000
A#-Bb	58.270
B	61.735

Octave 3

Note	Frequency
C	65.406
C#-Db	69.296
D	73.416
D#-Eb	77.782
E	82.407
F	87.307

Table 3-1. Equal Temperament Musical Scale (Cont.)

F#-Gb	92.499
G	97.999
G#-Ab	103.826
A	110.000
A#-Bb	116.541
B	123.471

Octave 4

Note	Frequency
C	130.813
C#-Db	138.591
D	146.832
D#-Eb	155.564
E	164.814
F	174.614
F#-Gb	184.997
G	195.998
G#-Ab	207.652
A	220.000
A#-Bb	233.082
B	246.942

Octave 5

Note	Frequency
C	261.626
C#-Db	277.183
D	293.665
D#-Eb	311.127
E	329.628
F	349.228
F#-Gb	369.994
G	391.995
G#-Ab	415.305
A	440.000
A#-Bb	466.164
B	493.883

Octave 6

Note	Frequency
C	523.251
C#-Db	554.365
D	587.330
D#-Eb	622.254

Table 3-1. Equal Temperament Musical Scale (Cont.)

E	659.255
F	698.456
F#-Gb	739.989
G	783.991
G#-Ab	830.609
A	880.000
A#-Bb	932.327
B	987.767

Octave 7

Note	Frequency
C	1046.502
C#-Db	1108.731
D	1174.659
D#-Eb	1244.508
E	1318.510
F	1396.913
F#-Gb	1479.978
G	1567.982
G#-Ab	1661.219
A	1760.000
A#-Bb	1864.655
B	1975.533

Octave 8

Note	Frequency
C	2093.005
C#-Db	2217.461
D	2349.318
D#-Eb	2489.016
E	2637.021
F	2793.826
F#-Gb	2959.955
G	3135.964
G#-Ab	3322.438
A	3520.000
A#-Bb	3729.310
B	3951.067

Octave 9

Note	Frequency
C	4186.010
C#-Db	4434.923

Table 3-1. Equal Temperament Musical Scale (Cont.)

D	4698.637
D#-Eb	4978.032
E	5274.041
F	5587.652
F#-Gb	5919.911
G	6271.927
G#-Ab	6644.876
A	7040.000
A#-Bb	7458.620
B	7902.133

Octave 10

Note	Frequency
C	8372.020
C#-Db	8869.845
D	9397.274
D#-Eb	9956.064
E	10548.080
F	11175.300
F#-Gb	11839.820
G	12543.850
G#-Ab	13289.750
A	14080.000
A#-Bb	14917.240
B	15804.270

Section 4

Radio Data

Radio Frequency Spectrum

Radio frequencies above 10,000 to 15,000 hertz are called radio frequencies (RF). Radio frequencies extend to 300,000,000,000 hertz and beyond. The spectrum of radio frequencies is divided into classifications for convenience. In the classifications of Table 4-1 below, a kilohertz (kHz) is a multiple of 1,000 hertz, a Megahertz (MHz) is a multiple of 1,000,000 hertz, and a Gigahertz (GHz) is a multiple of 1,000,000,000 hertz.

Table 4-1. Radio Frequency Spectrum

Frequency	Classification	Abbreviation
10 to 30 kHz	very-low frequency	vlf
30 to 300 kHz	low frequency	lf
300 to 3000 kHz	medium frequency	mf
3 to 30 MHz	high frequency	hf
30 to 300 MHz	very-high frequency	vhf
300 to 3000 MHz	ultrahigh frequency	uhf
3 to 30 GHz	superhigh frequency	shf
30 to 300 GHz	extremely high frequency	ehf

Types of Radio Emission, Amateur Radio and Other Services

Type	Description
A0 or N0N	Steady, unmodulated pure carrier with bandwidth of 0 hertz. Used for remote control. VHF freq-uencies and above
A1 or A1A	On and off keying of a continuous wave. Used for radio telegraphy, primarily for International Morse code. Usually referred to as CW. All frequencies. Bandwidth of approximately 150 hertz.
A2 or A2A	Amplitude tone-modulated telegraphy. Used for radio telegraphy for International Morse code on all frequencies voice transmission permitted. Approximately 2 kHz bandwidth.
A3 or 3E	AM. Amplitude modulation. Used for voice transmission. Extensively used for broadcastand "short wave" bands for commercial purposes. Little amateur use. Used on CB bands. Approximately 6 kHz bandwidth.
A3 or A3E	DSB suppressed carrier. Transmission of both sidebands with little or no carrier for voice. Approximately 6 kHz bandwidth. Little used.

A3H or H3E	SSB full carrier. Transmission of a single side-band with full carrier for voice. Reception compatible with AM. Approximately 3 kHz bandwidth. Some use on amateur bands and by commercial stations.
A3J or J3E	SSBSC. Single sideband, suppressed carrier. Transmission of only one sideband with little or no carrier for voice. Approximately 3 kHz bandwidth or less. Extensive use on all amateurbands, CB, and by other services.
A4	FAX: Facsimile. Transmission of an image by amplitude modulation. Widely used by commercial services, by the weather service, and moderate use by amateurs. Found on high-frequency (HF) bands and amateur bands. Approximately 6 kHz bandwidth.
A5	Television. Slow-scan television (SSTV) is found on high-frequency (HF) amateur bands and is used to transmit a video image in about 8 seconds. Approximately 3 kHz bandwidth. Fast-scan television is found on amateur bands above 420 MHz and for commercial use above 54 MHz. Approximately 6 to 8 MHz bandwidth.
F0	Same as A0.
F1 or F1B	Audio frequency shift telegraphy or Frequency Shift Keying (FSK). This transmission type is used for radio teletypewriter operation (RTTY), which is essentially telegraphy for automatic reception. Various types of RTTY are used on many high-frequency (HF) bands and above, both for amateur and commercial purposes. Typical bandwidths are 1 to 2 kHz.
F3	FM. Frequency modulation for voice. Used extensively by amateur, commercial, and government radio services, and for the audio portion of television transmission above 50 MHz. Typical bandwidths are 4 to 30 kHz.
F4	FM facsimile. Same uses as A4 transmission, but employing frequency modulation techniques.
G5	FM television. Same uses as A5 slow-scan television, but employing frequency modulation techniques.
P	Pulse emission. Used in the microwave region of the frequency spectrum; not used by amateurs at present.

Citizen's Band Radio

Three separate radio bands are set aside for Citizen's Band radio, communication between private individuals. The CB band from 72 to 76 MHz is used primarily for radio-control systems. The UHF CB band from 462.525 MHZ to 467.475 is shared with other services; voice and radio control is permitted. The CB band from 26.965 through 27.405 It allows for 40 channels, each 10 kHz wide. Standard amplitude modulation and single and double-sideband voice is allowed. The frequencies of each of the 40 channels is shown in Table 4-2.

Table 4-2. Eleven-Meter Citizens Band Frequencies

Channel #	Frequency	
1	26.965 MHz	(single owner)
2	26.975	″ ″
3	26.985	″ ″
4	27.005	″ ″
5	27.015	″ ″
6	27.025	″ ″
7	27.035	″ ″
8	27.055	
9	27.065	(emergency)
10	27.075	
11	27.085	
12	27.105	
13	27.115	
14	27.125	
15	27.135	
16	27.155	(single owner)
17	27.165	″ ″
18	27.175	″ ″
19	27.185	″ ″
20	27.205	″ ″
21	27.215	″ ″
22	27.225	″ ″
23	27.255	
24	27.235	
25	27.245	
26	27.265	
27	27.275	
28	27.285	
29	27.295	
30	27.305	
31	27.315	
32	27.325	
33	27.335	

Table 4-2. Eleven-Meter Citizens Band Frequencies (Cont.)

34	27.345
35	27.355
36	27.365
37	27.375
38	27.385
39	27.395
40	27.405

Single owner channels
authorized only for use
between stations of a
single owner.

Amateur Radio Operator Privileges

Amateur radio operators operate on a wide range of frequency bands and with a variety of types of transmission—telegraphy, voice, television, and other modes. All activity is for non-commercial purposes without remuneration. The purpose of amateur radio is to advance the provide a pool of skilled radio operators. There are five classes of amateur radio operator licenses (there is also a station license which establishes the primary location of the amateur radio station). The five operator licenses are graduated in privileges. The five types of operator licenses, listed in order of privileges, are:

- Novice class
- Technician class
- General class
- Advanced class
- Amateur Extra class

Applicants must be U.S. citizens or other U.S. nationals. There are no other major restrictions. Operator licenses are obtained by passing an examination made up of both a written portion and a code test as follows:

- Novice: 5 word per minute code test, written test of elementary theory and regulations
- Technician: 5 word per minute code test, written test of both elementary and general theory and regulations
- General: 13 word per minute code test, written testof both elementary and general theory and regulations
- Advanced: 13 word per minute code test, written test of general theory and regulations, written test of intermediate theory
- Extra: 20 word minute code test, written test of general theory and regulations, written test of intermediate theory, written test of advanced techniques.

Tests are administered by volunteer examiners who hold valid amateur radio licenses. Novice tests may be given by a General class licensee or above who is 18 years of age or older, not a relative of the applicant, and has non-commercial amateur radio interests. Tests for technician class and above must be given by FCC-accredited volunteer examiners. Tests for Technician class and above are given by FCC-accredited volunteer examiners. Tests for Technician class and above are given regulary by amateur radio clubs or associations in many areas.

General privileges for each class are as follows:

- Extra Class: All amateur privileges including selected portions of amateur bands not available to other classes
- Advanced class: All amateur privileges except Extra class privileges, including selected portions of amateur bands not available to General class and below
- General class: All amateur privileges except those reserved for Advanced and Extra Class. These privileges constitute the bulk of the amateur bands
- Technician class: All amateur privileges above 50 MHz plus Novice privileges
- Novice class: Telegraphy in certain portions of the 75 meter, 40 meter, 15 meter, and 10 meter bands

Amateur ("Ham") Bands

Amateur radio operators are permitted use of the radio frequency spectrum for non-commercial purposes. Amateur radio (or "ham" radio) operations are carried out for experimentation, emergency communications, and hobby purposes in many countries of the world. Modes of operation range from telegraphy and a.m. voice to amateur television, satellite, and digital communications. Table 4-3 lists the amateur bands permitted in the U.S. Other countries have similar allocations. For convenience, the frequency bands are called by their equivalent wavelength.

Table 4-3. Amateur ("Ham") Bands

Band (meters)	Frequency Range (MHz)
160	1.8 - 2.0
80, 75	3.5 - 4.0
40	7.0 - 7.3
30	10.1 - 10.15
20	14.0 - 14.35
17	19.068 - 18.168
15	21.0 - 21.45
12	24.89 - 24.99
10	28.0 - 29.7
6	50.0 - 54.0
2	144.0 - 148.0
1 1/4	220 - 225
3/4	420 - 450

Table 4-3. Amateur ("Ham") Bands (Cont.)

1240 - 1300
2300 - 2450
3300 - 3500
5650 - 5925
Frequency Range (GHz)
10.0 - 10.5
24.0 - 24.25
48 - 50
71 - 76
165 - 170
240 - 250
300 and above

International Q Signals

Q signals are abbreviations for common messages. Q signals are most often used in CW (code) operation among radio amateurs, although many are also used as a form of shorthand in radio telephony. Common Q signals are shown in Table 4-4. When intitiated, the Q Signal takes the form of a question. When answered, the response to the question. The structure of the Q signal is not exact, as in these examples: "QSY up 5 kc.," "I have a QRP rig," and "Lots of QRN on that last transmission."

Table 4-4. Q Signals

Signal	Question	Response
QRG	What is my exact frequency?	Your exact frequency is — —.
QRH	Does my frequency vary?	Your frequency varies.
QRI	How is my tone?	Your tone is (1-5; bad-good).
QRK	What is my readability?	Your readability is (1-5; bad-good).
QRL	Are you busy?	I am busy.
QRM	Is there interference?	There is interference.
QRN	Is there static?	There is static.
QRO	Shall I increase power?	Increase power.
QRP	Shall I decrease power?	Decrease power.
QRQ	Shall I send faster?	Send faster at — — (wpm).
QRS	Shall I send more slowly?	Send more slowly at — — (wpm).
QRT	Shall I stop sending?	Stop sending.
QRU	Have you anything for me.	I have nothing for you.
QRV	Are you ready?	I am ready.
QRX	When will you call again?	At — — hours on — — frequency.
QSA	What is my signal strength?	Your strength is (1-5; bad-good).

Table 4-4. Q Signals (Cont.)

QSB	Am I fading?	You are fading.
QSD	Are my signals defective?	Your signals are defective.
QSG	Shall I send —— messages?	Send —— messages at one time.
QSK	Do you have break in?	I have break in.
QSL	Will you acknowledge receipt?	I acknowledge receipt.
QSM	Shall I repeat the message?	Repeat the last (or ——) message.
QSN	Did you hear me on ——?	I heard you on —— (frequency).
QSO	Can you communicate with ——?	I can communicate with ——.
QSP	Will you relay to ——?	I will relay to ——.
QST	General call to ARRL members.	——
QSU	Shall I send on —— (freq.)?	Send on —— (frequency).
QSV	Shall I send a series of Vs?	Send a series of Vs.
QSW	Will you send on —— (freq)?	Send on —— (frequency).
QSX	Will you listen on —— (freq)?	I will listen on —— (frequency).
QSY	Shall I change to —— (freq)?	Change to —— (frequency).
QSZ	Shall I send each word group more than once?	Send each word group —— times.
QTA	Shall I cancel message ——?	Cancel message ——.
QTB	Do you agree with my word count?	I agree with your word count.
QTC	How many messages do you have?	I have —— messages.
QTH	What is your location?	My location is ——.
QTR	What is the correct time?	The correct time is ——.

"10" Signals

"10" codes are special abbreviations used for brevity or security reasons. There is a wide variation in the codes used, however. The codes used by the Associated Public Safety Communications Officers, Inc. are used by many local, county, state, and federal agencies. They are shown in Table 4-5.

Table 4-5. APCO 10 Codes

10-0	Caution
10-1	Unable to copy, change location
10-2	Signal good
10-3	Stop transmitting
10-4	Ok, Acknowledgement
10-5	Relay
10-6	Busy, unless urgent
10-7	Out of service
10-8	In service
10-9	Repeat
10-10	Fight in progress
10-11	Dog case

Table 4-5. APCO 10 Codes (Cont.)

10-12	Stand by, stop
10-13	Weather and road conditions
10-14	Prowler report
10-15	Civil disturbance
10-16	Domestic problem
10-17	Meet complainant
10-18	Complete assignment quickly
10-19	Return to station or...
10-20	Location
10-21	Call...by telephone
10-22	Disregard
10-23	Arrived at scene
10-24	Assignment completed
10-25	Report in person, meet
10-26	Detaining subject, expedite
10-27	Drivers license information
10-28	Vehicle registration information
10-29	Check records for wanted or stolen
10-30	Unnecessary use of radio
10-31	Crime in progress
10-32	Man with gun
10-33	Emergency
10-34	Riot
10-35	Major crime alert
10-36	Correct time
10-37	Investigate suspicious vehicle
10-38	Stopping suspicious vehicle
10-39	Urgent, use light and siren
10-40	Silent run, no light or siren
10-41	Beginning tour of duty
10-42	Ending tour of duty
10-43	Information
10-44	Permission to leave...for...
10-45	Animal carcass
10-46	Assist motorist
10-47	Emergency road repair
10-48	Traffic standard repair
10-49	Traffic light out
10-50	Accident
10-51	Wrecker needed
10-52	Ambulance needed
10-53	Road blocked
10-54	Livestock on highway
10-55	Intoxicated driver

Table 4-5. APCO 10 Codes (Cont.)

10-56	Intoxicated pedestrian
10-57	Hit and run
10-58	Direct traffic
10-59	Convoy or escort
10-60	Squad in vicinity
10-61	Personnel in area
10-62	Reply to message
10-63	Prepare to make written copy
10-64	Message for local delivery
10-65	Net message assignment
10-66	Message cancellation
10-67	Clear for net message
10-68	Dispatch information
10-69	Message received
10-70	Fire alarm
10-71	Advise nature of fire
10-72	Report progress of fire
10-73	Smoke report
10-74	Negative
10-75	In contact with...
10-76	En route to...
10-77	Estimated Time of arrival
10-78	Need assistance
10-79	Notify coroner
10-80	Chase in progress
10-81	Breatherlizer report
10-82	Reserve lodging
10-83	Work school crossing at...
10-84	If meeting...advise ETA
10-85	Delayed due to...
10-86	Officer/operator on duty
10-87	Pick up/distribute checks
10-88	Present telephone number of...
10-89	Bomb threat
10-90	Bank alarm
10-91	Pick up prisoner/subject
10-92	Improperly parked vehicle
10-93	Blockade
10-94	Drag racing
10-95	Prisoner/subject in custody
10-96	Mental subject
10-97	Check signal
10-98	Prison/jail break
10-99	Wanted or stolen indicated

WWV, WWVH, WWVB Standard Time and Frequency Signals

The National Bureau of Standards broadcasts time signals on precise frequencies from three stations. Time signals are broadcast both in voice and digitally encoded form. Time is given in 24-hour clock Coordinated Universal Time. (Local time at Greenwich, England.)

WWV: Located at Fort Collins, Colorado, this station operates on 2.5, 5, 10, 15, and 20 MHz with an accuracy of 1 part in 10^{12}. However, radio wave propagation effects will result in a received accuracy several magnitudes less than this.

Format: Clock ticks every second superimposed over 600 hertz tone (odd minutes) or 500 hertz tone (even minutes). Clock ticks are 5 milliseconds of 1000 hertz tone. The 29th and 59th clock ticks are suppressed. The tone sounds for the first 45 seconds of every minute. There is a male voice announcement of the time each minute after 52.5 seconds. The voice announcement is "At the tone, hours, minutes, Coordinated Universal Time." At the minute mark, a 1000-hertz tone sounds for 0.8 seconds. At the hour mark, a 1500-hertz tone sounds for 0.8 seconds. Voice station identification is done at the half hour and hour marks. Other announcements, including weather and radio propagation information, are done at various times.

WWVH: Located at Kauai, Hawaii, this station operates on 2.5, 5, 10, and 15 MHz with the same accuracy as WWV.

Format: Clock ticks every second superimposed over 600 hertz tone (even minutes) or 500 hertz tone (odd minutes). Clock ticks are 5 milliseconds of 1200 hertz tone. The 29th and 59th clock ticks are suppressed. The tone sounds for the first 45 seconds of every minute. There is a female voice announcement of the time each minute after 45 seconds. The voice announcement is "At the tone, --hours, --minutes, Coordinated Universal Time." At the minute mark, a 1000-hertz tone sounds for 0.8 seconds. At the hour mark, a 1500-hertz tone sounds for 0.8 seconds.

Time Code Data: Time code information is broadcast by WWV and WWVH simultaneously with the audio information on a 100 hertz subcarrier, in binary-coded-decimal format. The current minute, hour, and day of the year are continuously sent.

WWVB: Station WWVB broadcasts a continuous time code on a frequency of 60 kHz. No voice information is sent.

CHU Time and Frequency Signals

The National Research Council of Canada broadcasts time signals on 3.330, 7.335, and 14.670 MHz. Clock ticks are 300 cycles of a 1000-hertz tone (0.3 seconds). The 29th and 51st to 59th ticks are suppressed. At the minute mark, the 1000-hertz tone is broadcast for 0.5 seconds. At the hour mark, the tone is broadcast for 1 second. A voice announcement of the time is made 50 seconds after each minute.

Foreign Broadcast Bands

Radio and other types of broadcasting is governed by international regulations. The radio-frequency spectrum is divided into ranges of frequences and certain of these ranges are used for "short-wave" broadcasting, either by stations sponsored by countries themselves or by commercial enterprises. Table 4-6 lists the foreign broadcast bands of the radio spectrum. Unless otherwise noted, broadcasting is done in amplitude-modulation (am) mode. Bands shared with other services are marked with an asterisk.

Table 4-6. Foreign Broadcast Bands

148.5 - 283.5	kHz	European stations*
526.5 - 1606.5		Europe, Middle East, Africa, Asia; North, Central, and South America
2.300 - 2.498	MHz	Tropical broadcasting
3.200 - 3.400		Tropical broadcasting
3.900 - 4.000		World-wide broadcasting*
4.750 - 5.060		Tropical broadcasting*
5.950 - 6.200		World-wide broadcasting
7.100 - 7.300		World-wide broadcasting*
9.500 - 9.750		World-wide broadcasting
9.750 - 9.900		World-wide broadcasting*
11.650 - 11.700		World-wide broadcasting*
11.700 - 11.975		World-wide broadcasting
11.975 - 12.050		World-wide broadcasting*
13.600 - 13.800		World-wide broadcasting*
15.100 - 15.450		World-wide broadcasting
15.450 - 15.600		World-wide broadcasting*
17.550 - 17.700		World-wide broadcasting*
17.700 - 17.900		World-wide broadcasting
21.450 - 21.750		World-wide broadcasting
21.750 - 21.850		World-wide broadcasting*
25.670 - 26.100		World-wide broadcasting
47 - 68		World-wide VHF television*
87.5 - 108		World-wide fm broadcasting*
174 - 230		World-wide VHF television*
470 - 960		World-wide UHF television*

* = shared with other services

International Morse Code

Table 4-7 shows the International Morse Code. This code uses two elements of unequal length, a *dot* and a *dash*. The length of the dash is three times that of a dot. Spaces between dots and dashes in the same character are equal to the length of one dot. Spaces between characters are equal to the length of three dots. Spaces between words or groups are equal to the length of seven dots. These relationships are shown in Figure 4-1. Character coding is based upon frequency of occurrence of letters in the English language. The speed of transmission is equal to

Speed (words per minute) = 2.4 x (# of dots per second)

Table 4-7. International Morse Code (Most Common Characters)

Letters	
A	.-
B	-...
C	-.-.
D	-..
E	.
F	..-.
G	--.
H	....
I	..
J	.---
K	-.-
L	.-..
M	--
N	-.
O	---
P	.--.
Q	--.-
R	.-.
S	...
T	-
U	..-
V	...-
W	.--
X	-..-
Y	-.--
Z	--..

Digits	
0	-----
1	.----
2	..---
3	...--
4	....-
5	.....
6	-....
7	--...
8	---..
9	----.

Special Characters	
period	.-.-.-
comma	--..--
? (question mark)	..--..
dash	-...-
slash	-..-.

Operating Characters	
error	....
wait	.-...
end of message	.-.-.
go ahead	-.-
end of session	...-.-

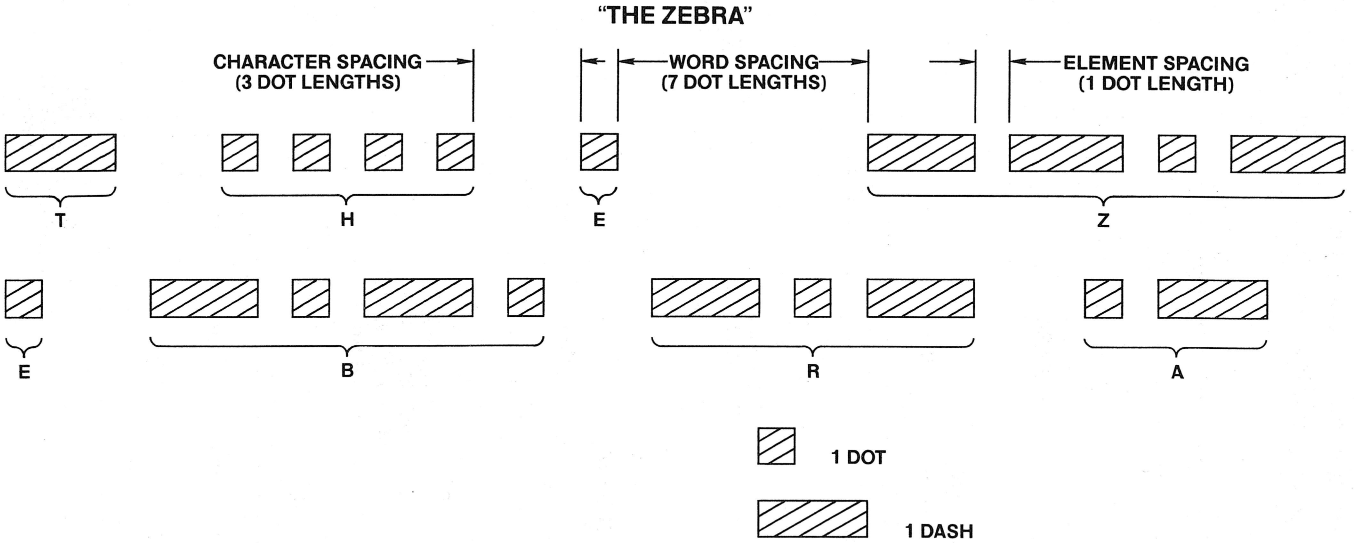

"THE ZEBRA"
CHARACTER SPACING (3 DOT LENGTHS)
WORD SPACING (7 DOT LENGTHS)
ELEMENT SPACING (1 DOT LENGTH)
T
H
E
Z
E
B
R
A
1 DOT
1 DASH

Figure 4-1. International Morse Code Timing

Common Antenna Types

Figure 4-2 shows common antenna configurations, suitable for use at frequencies below 30 MHz. For higher frequencies, the dimensions are approximately correct.

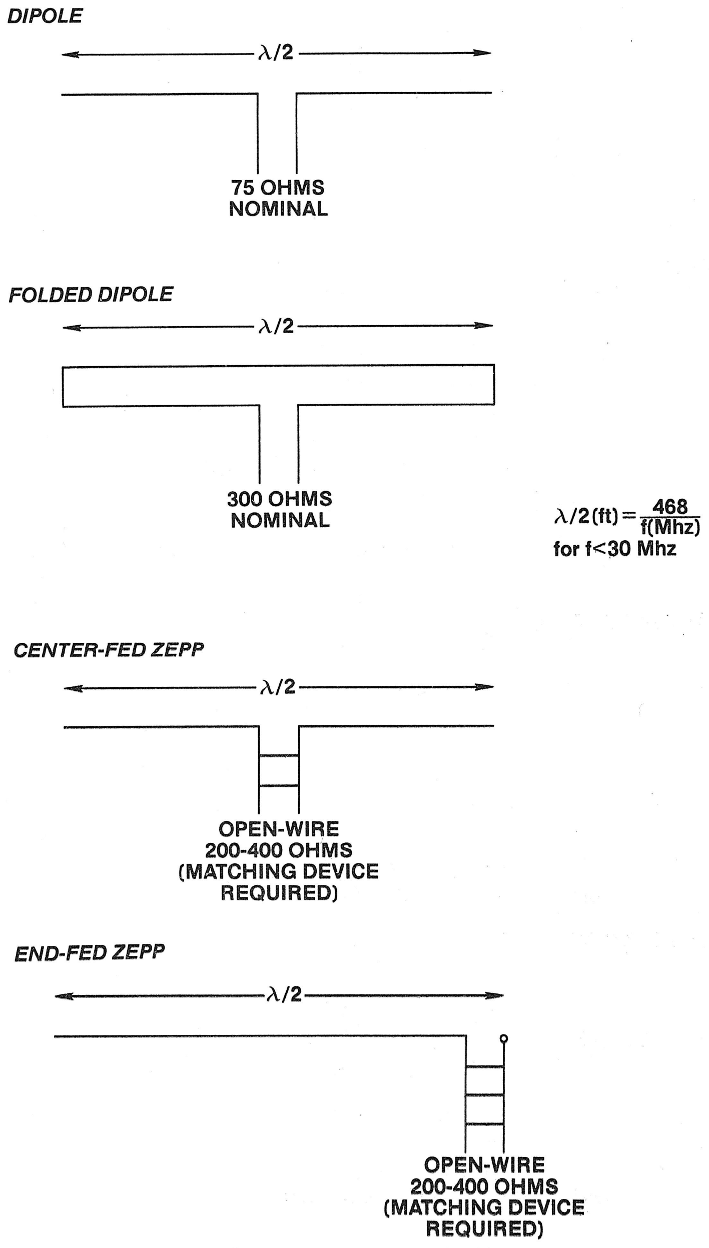
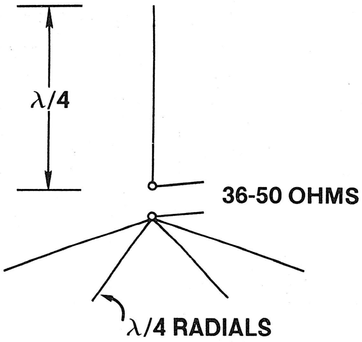
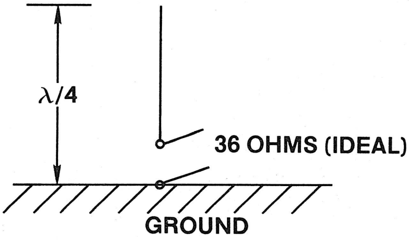


Figure 4-2. Common Antenna Types

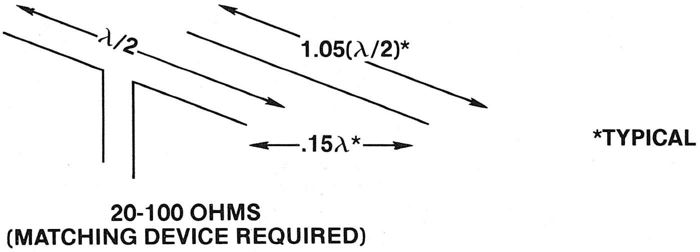
GROUND PLANE VERTICAL



VERTICAL



TWO ELEMENT BEAM



THREE ELEMENT BEAM

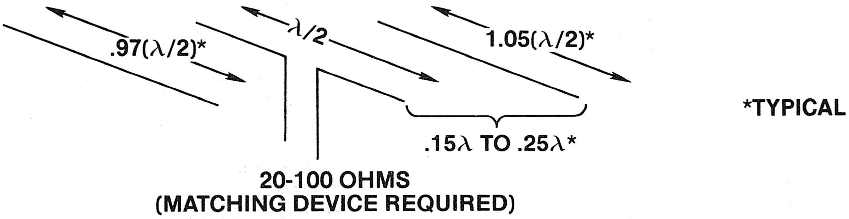


Figure 4-2. Common Antenna Types (cont.)

Section 5

Television Data

Television Signal Standards

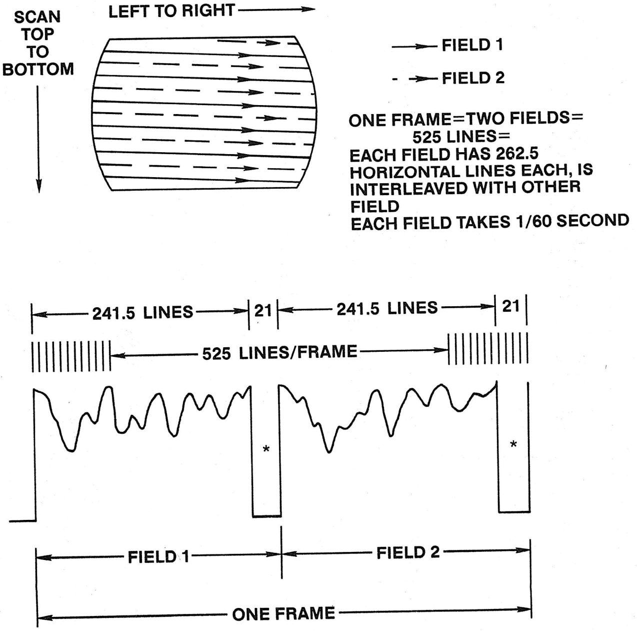
Figure 5-1 shows the format for standard television signals, black and white (monochrome) and color as used in the United States. The basic signal provides for 525 lines per television frame, each frame being made up of two fields of 262.5 lines each. Each field displays alternate lines. Each field takes about 1/60th of a second (59.94 seconds for color). Each line takes approximately 63.5 microseconds.

The television tube beam sweeps across the screen from top to bottom and from left to right. Each line is at a slight angle. Each line takes approximately 63.5 microseconds to travel across the screen and back.

The lines are synchronized by sync pulses that occur at the line rate. Their level is "blacker" than the black level. The blanking level (blanks out the beam) is 75.0 ± 2.5 percent of peak carrier level. The reference black level is 92.5 ± 2.5 percent of the blanking level. The white level is 12.5 ± 2.5 percent of the peak carrier level.

A 3.579545 MHz color sync burst occurs at the "back porch" of every sync pulse. This color sync burst is omitted for monochrome transmission.

The vertical blanking interval occurs during the last 21 lines of each field. No picture occurs during this time. During this interval the beam returns to the top of the picture. Also during this interval, a number of coded signals may be present. These include FCC test signals, network test signals, captioning for the deaf, or videotext signals.



*VERTICAL INTERVAL FOR BEAM REPOSITIONING TO TOP OF SCREEN

Figure 5-1. Television Signal Format

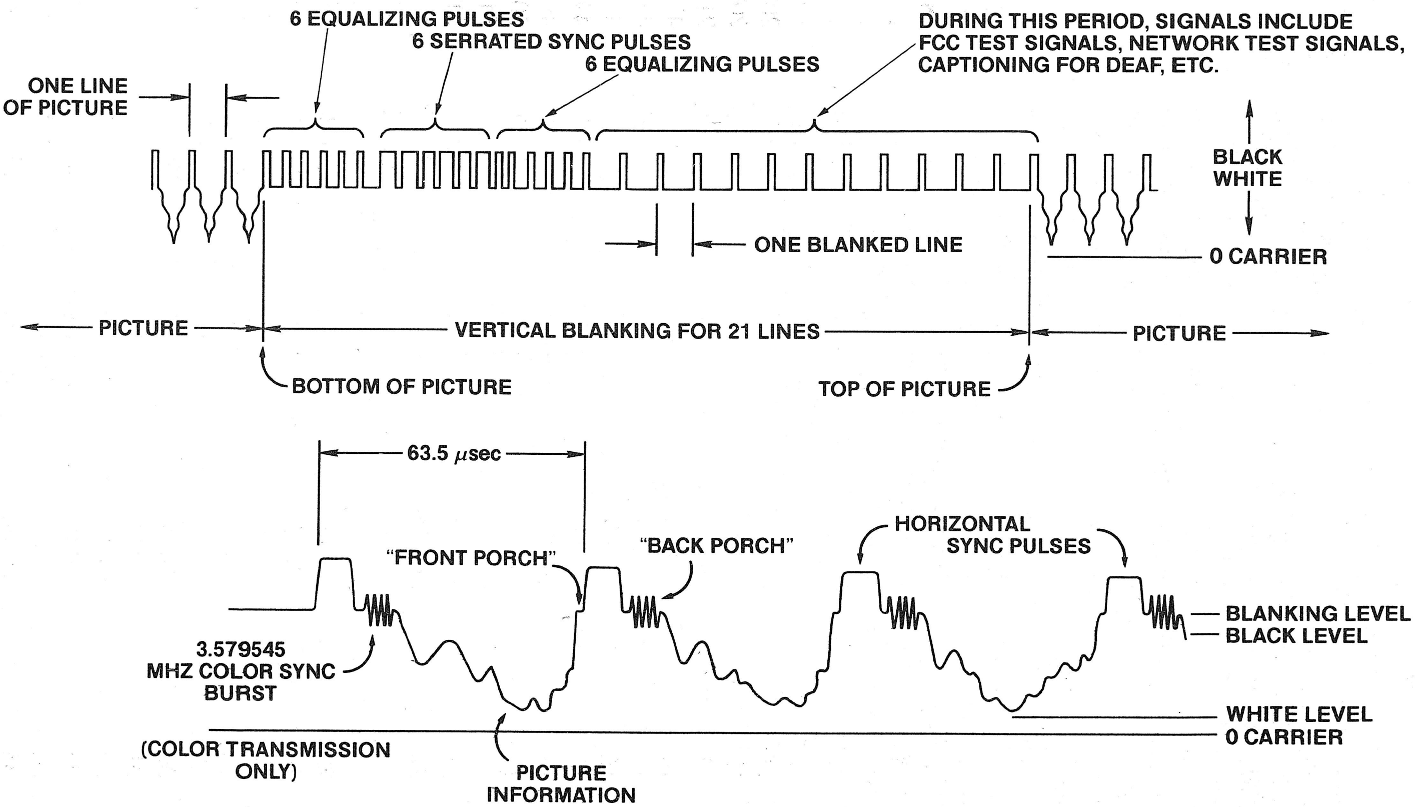


Figure 5-1. Television Signal Format (cont.)

Television Channel Frequencies.

Table 5-1 lists the frequencies of television channels, both vhf (very high frequency) and uhf (ultra high frequency). Note the gaps in frequencies between channels 2-4, 5-6, 7-13, and 14-83. Video is amplitude modulated, suppressed lower sideband. Audio is frequency modulated. The video and audio carrier frequencies within each channel are listed separately. All frequencies are in megahertz (Mhz).

Table 5-1. Television Channel Frequencies

Channel	Limits (Mhz)		Video Carrier	Audio Carrier
2	54.00	60.00	55.25	59.75
3	60.00	66.00	61.25	65.75
4	66.00	72.00	67.25	71.75
5	76.00	82.00	77.25	81.75
6	82.00	88.00	83.25	87.75
7	174.00	180.00	175.25	179.75
8	180.00	186.00	181.25	185.75
9	186.00	192.00	187.25	191.75
10	192.00	198.00	193.25	197.75
11	198.00	204.00	199.25	203.75
12	204.00	210.00	205.25	209.75
13	210.00	216.00	211.25	215.75
14	470.00	476.00	471.25	475.75
15	476.00	482.00	477.25	481.75
16	482.00	488.00	483.25	487.75
17	488.00	494.00	489.25	493.75
18	494.00	500.00	495.25	499.75
19	500.00	506.00	501.25	505.75
20	506.00	512.00	507.25	511.75
21	512.00	518.00	513.25	517.75
22	518.00	524.00	519.25	523.75
23	524.00	530.00	525.25	529.75
24	530.00	536.00	531.25	535.75
25	536.00	542.00	537.25	541.75
26	542.00	548.00	543.25	547.75
27	548.00	554.00	549.25	553.75
28	554.00	560.00	555.25	559.75
29	560.00	566.00	561.25	565.75
30	566.00	572.00	567.25	571.75
31	572.00	578.00	573.25	577.75
32	578.00	584.00	579.25	583.75
33	584.00	590.00	585.25	589.75
34	590.00	596.00	591.25	595.75
35	596.00	602.00	597.25	601.75

Table 5-1. Television Channel Frequencies (Cont.)

Channel	Limits (Mhz)		Video Carrier	Audio Carrier
36	602.00	608.00	603.25	607.75
37	608.00	614.00	609.25	613.75
38	614.00	620.00	615.25	619.75
39	620.00	626.00	621.25	625.75
40	626.00	632.00	627.25	631.75
41	632.00	638.00	633.25	637.75
42	638.00	644.00	639.25	643.75
43	644.00	650.00	645.25	649.75
44	650.00	656.00	651.25	655.75
45	656.00	662.00	657.25	661.75
46	662.00	668.00	663.25	667.75
47	668.00	674.00	669.25	673.75
48	674.00	680.00	675.25	679.75
49	680.00	686.00	681.25	685.75
50	686.00	692.00	687.25	691.75
51	692.00	698.00	693.25	697.75
52	698.00	704.00	699.25	703.75
53	704.00	710.00	705.25	709.75
54	710.00	716.00	711.25	715.75
55	716.00	722.00	717.25	721.75
56	722.00	728.00	723.25	727.75
57	728.00	734.00	729.25	733.75
58	734.00	740.00	735.25	739.75
59	740.00	746.00	741.25	745.75
60	746.00	752.00	747.25	751.75
61	752.00	758.00	753.25	757.75
62	758.00	764.00	759.25	763.75
63	764.00	770.00	765.25	769.75
64	770.00	776.00	771.25	775.75
65	776.00	782.00	777.25	781.75
66	782.00	788.00	783.25	787.75
67	788.00	794.00	789.25	793.75
68	794.00	800.00	795.25	799.75
69	800.00	806.00	801.25	805.75
70	806.00	812.00	807.25	811.75
71	812.00	818.00	813.25	817.75
72	818.00	824.00	819.25	823.75
73	824.00	830.00	825.25	829.75
74	830.00	836.00	831.25	835.75
75	836.00	842.00	837.25	841.75
76	842.00	848.00	843.25	847.75
77	848.00	854.00	849.25	853.75

Table 5-1. Television Channel Frequencies (Cont.)

Channel	Limits (Mhz)		Video Carrier	Audio Carrier
78	854.00	860.00	855.25	859.75
79	860.00	866.00	861.25	865.75
80	866.00	872.00	867.25	871.75
81	872.00	878.00	873.25	877.75
82	878.00	884.00	879.25	883.75
83	884.00	890.00	885.25	889.75

Section 6

Electronics Data

Dielectric Constants of Materials

The dielectric constant of a material defines its electrical insulating quality. The dieletric constant varies for different types of materials and for temperature and frequencies. Table 6-1 shows the approximate dielectric constants for common materials. The dielectric constant for air is very close to 1.

Table 6-1. Dielectric Constants

Material	Approximate Dielectric Constant
Air	1.0
Aluminum oxide	6-8
Bakelite	4.5-5
Glass	8
Mica	2.5-7
Mylar	3.2
Neoprene	4.1
Nylon	3.5
Paper	1.5-3
Polyester	4.1-5.2
Polyethylene	2.3
Quartz	4.3
Rubber, hard	2.8
Tantalum pentoxide	6-8
Teflon	2.1
Vinyl chloride	3.5-4.5
Water	78.5
Wood	1.4-2.9

Coaxial Cable Characteristics

Table 6-2 provides data on the characteristics of commonly used types of coaxial cable. The velocity factor of the cable is the transmission speed relative to open wire line. The capacitance per foot is the nominal capacitance in picofarads per foot of cable. The attenuation is the signal loss in decibels per 100 feet of cable at a frequency of 100 MHz.

Table 6-2. Coaxial Cable Characteristics

Type RG–..	Nominal Impedance (Ohms)	Outside Diameter (Inches)	Velocity Factor	Capacitance/ Foot	Attenuation/ 100 Ft. @ 100 MHz
6/U	75	.266	.75	18.6	1.8
8/U	52	.405	.66	29.0	3.5
8/M	52	.242	.75	26.0	3.0
58/U	52	.196	.66	28.0	5.3
59/U	75	.242	.66	21.0	2.9
62A/U	93	.242	.84	13.5	4.4
174	50	.10	.66	30.0	9.0

Letter Symbols and Abbreviations

Table 6-3 shows letter symbols for electrical and other units and quantities. Many of them are used internationally, regardless of the language. The table also shows common English language abbreviations for electrical terms, some of which are used in other languages.

Table 6-3. Letter Symbols and Abbreviations

μ — Mico (10^{-6})
μA — Microampere
μF — Microfarad
μH — Microhenry
μm — Micrometer
μp — Microprocessor
μs — Microsecond
° — Degree (plane angle)
′ — Minute (plane angle)
″ — Second (plane angle)
°C — Degree celsius
°F — Degree Fahrenheit
°R — Degree Rankine
1/c — Single conductor
3/c — Three-conductor
3p — Three-pole
3pdt sw — Three-pole, double-throw switch
3pdt — Three-pole, double-throw
3ph — Three-phase
3pst sw — Three-pole, single-throw switch
3pst — Three-pole, single-throw
3w — Three way
3way — Three way

Table 6-3. Letter Symbols and Abbreviations (Cont.)

4/c — Four conductor
4p — Four-pole
4pdt sw — Four-pole, double-throw switch
4pdt — Four-pole, double-throw
4pst sw — Four-pole, single-throw switch
4pst — Four-pole, single-throw
4w — Four-wire
4way — Four-way
A — Ampere; ampere turn
A — Angstrom (micrometer)
a — Atto (10^{-18})
A/D — Analog-to-Digital
A/m — Ampere per meter
ac — Alternating current
adc — Analog-to-digital converter
af — Audio frequency
afc — Automatic frequency control
agc — Automatic gain control
Ah — Ampere-hour
ALU — Arithmetic-logic unit
am — Amplitude modulation
amp hr — Ampere hour
amp — Ampere
ampl — Amplifier
ant — Antenna
apc — Automatic phase control
assy — Assembly
atten — Attenuation; attenuator
auto — Automatic; automobile
aux — Auxiliary
avc — Automatic volume control
avg — Average
AWG — American Wire Gauge
B — bel
b — bit; Barn
B&S — Brown and Sharpe Wire Gauge
bal — Balance
bc — Broadcast
Bd — Baud
bfo — Beat frequency oscillator
bit — Binary digit
bp — Bandpass
bps — Bits per second
Bq — Becquerel

Table 6-3. Letter Symbols and Abbreviations (Cont.)

Btu — British thermal unit
bw — Bandwidth
byp — Bypass
C — Capacitance, capacitor, collector, coulomb
c — Centi(10^{-2}); cycle
c/s — Cycle per second (hertz)
c/s — Cycles per second
cal — Calibrate
cap — Capacitor
cath — Cathode
cb — common base
cc — Color Code
cd — Candela
cd/m^2 — Cubic centimeter
ce — Common emitter
cf — Cathode follower
chan — Channel
ci — Curie (bequerel)
ckt — Circuit
cm^3 — Cubic centimeter
cm — Centimeter
cmil — Circular mil
CMOS — Complementary metal-oxide semiconductor
cr — Carriage return
crt — Cathode-ray tube
ct — Center tap
cw — Continuous wave
cy — cycle
D — Drain; duty factor; electric flux density
d — Deci(10^{-1})
D/A — Digital to analog
da — Deka (10)
dac — Digital-to-analog converter
dB — Decibel
db — Double break
dblr — Doubler
dc — Direct current
dcc — double cotton covered
DCTL — Direct-coupled transistor logic
deg — Degree
demod — Demodulator
det — Detail; detach
df — Direction finder
disc — Disconnect

Table 6-3. Letter Symbols and Abbreviations (Cont.)

DMA — Direct memory access
dmgz — Demagnetize
dmr — Dimmer
dp — Double-pole
dpbc — Double-pole, back-connected
dpdt — Double-pole, double-throw
dpfc — Double-pole, front connected
dplxr — Duplexer
dpst — Double-pole, single-throw
dpsw — Double-pole switch
DRAM — Dynamic random-access memory
dsb — Double-sideband
dsc — Double silk-covered
dssb — Double single sideband
dt — Double throw
DTL — Diode-transistor logic
dtvm — Differential thermocouple voltmeter
dty cy — Duty cycle
dyn — Dynamo
dyn — Dyne (newton)
dynm — Dynamometer
dynmt — Dynamometer
E — East; emitter; voltage
E — Exa (10^{18})
ec — enamel covered
ECL — Emitter-coupled logic
edt — Electronic discharge tube
ef — Emitter follower
elctd — Electrode
emf — Electromotive force
emsn — Emission
emt — Electrical metallic tubing
emtr — Emitter
engy — Energy
env — Envelope
ep — Epitaxial planar
er — Electrical resistance
erg — erg (joule)
erp — Effective radiated power
es — Electrostatic
eV — Electronvolt
evm — Electronic voltmeter
evom — Electronic voltohmmeter
exctr — Exciter

Table 6-3. Letter Symbols and Abbreviations (Cont.)

F — Farad
f — Femto (10^{-15}); frequency; force
fb — Fuse block
fc — Footcandle (lux)
fdbk — Feedback
FET — Field-effect transistor
ff — Flip-Flop
fil — Filament
fL — Footlambert (candela per square meter)
fm — Frequency modulation
foc — Focus
freq chg — Frequency changer
freq con — Frequency converter
freqm — Frequency meter
fsc — Full scale
ft^2 — Square foot
ft^3 — Cubic foot
ft^3/min — Cubic feet per minute
ft^3/s — Cubic feet per second
ft — Foot
ft — lbf-Foot-pound force
ft/min — Feet per minute
ft/s^2 — Feet per second squared
ft/s — Feet per second
fu — Fuse
fw — Full wave
G — Gain; gate
G — Giga (10^9); Gauss (tesla)
g — Gram
g — Grounded
g/cm^2 — Gram per cubic centimeter
gal — Gallon
galvnm — Galvanometer
Gb — Gilbert (ampere turn)
gdlk — Grid leak
GeV — Gigaelectronvolt
GHz — Gigahertz
GMT — Greewich mean time
gnd — Ground
gr — Gram
Gy — Gray
H — Henry
h — hecto (10^2); hour
hdst — Headset

Table 6-3. Letter Symbols and Abbreviations (Cont.)

hex — Hexadecimal
hf — high frequency
hfo — high-frequency oscillator
hi fi — High fidelity
hp — High pass; high pressure; horsepower
hp — Horsepower (watt)
hsd — Hot side
ht — High tension
HTL — High-threshold logic
hv — High voltage
hvr — High-voltage regulator
hyb — Hybrid
hyp — Hypotenuse
Hz — Hertz
I — Current
I^2L — Integrated injection logic
I/O — Input/output
IC — Integrated circuit
id — Inside diameter
if — Intermediate frequency
IGFET — Insulated-gate field effect transistor
illum — Illuminate
impd — Impedance
in^2 — Square inch
in^3 — Cubic inch
in — inch
in/s — Inch per second
incand — Incandescent
incr — Increase; increment
ind lp — Indicating lamp
ind — indicate
inf — infinite; infinity
inp — Input
insp — Inspect
inst — Install; installation
instm — Instrumentation
instr — Instrument
insul — Insulate; insulation
intercom — Intercommunicating; intercommunication
inv — Inverter
J — Joule
J/K — Joule per kelvin
JAN — Joint Army-Navy
JANAF — Joint Army-Navy-Air Force

Table 6-3. Letter Symbols and Abbreviations (Cont.)

jb — Junction box
jct — Junction
JFET — Junction field-effect transistor
jk — Jack
K — Kilo (10^2); Kelvin
kΩ — Kilohm
k — Dielectric constant
kg — Kilogram
kHz — Kilohertz
km — Kilometer
km/h — Kilometer per hour
ko — Knock out
kV — Kilovolt
kVA — Kilovoltampere
kW — Kilowatt
kWh — Kilowatt-hour
KWhm — Kilowatt-hour meter
l — Liter; lambert (candela per meter^2)
l=Length; inductance; inductor; luminance
lb — pound
lcd — Liquid crystal display
lf — Low frequency; line feed
lfo — Low-frequency oscillator
lh — Left hand
lim sw — Limit switch
lim — Limit
lkg — Leakage
llres — Load-limiting resistor
lm — Lumen
lm-s — Lumen second
lm/m^2 — Lumen per square meter
lm/w — Lumen per watt
lo — Local oscillator
lpo — Low power output
lr — Load resistor (relay)
lsb — Lower sideband; least significant bit
LSHI — Large-scale hybrid integration
LSI — Large-scale integration
lsr — Load-switching resistor
lt sw — Light switch
lx — Lux(lm/m^2)
lyr — Layer
M — Mega (10^2)
m — meter; milli (10^3); magnaflux; mode

Table 6-3. Letter Symbols and Abbreviations (Cont.)

MΩ — Megohm
m^2 — Square meter
m^3 — Cubic meter
m^3/s — Cubic meter per second
M/S — Master/slave (flip-flop)
mA — Milliampere
ma — Mercury arc
mag amp — Magnetic amplifier
mag mod — Magnetic modulator
mag — Magnet; magnetic
mc — Momentary contact; multichip
mdl — Module
MeV — Megaelectronvolt
mf — Microfilm
mg — Magnetic armature
mgn — Magneto; magnetron
mH — Millihenry
mho — Mho (siemens)
MHz — Megahertz
mi/h — Mile per hour
mic — Microphone
mil — Mil (0.001 inch)
min — Minute (time)
mL — Milliliter
mm — Millimeter
mol — Mole
mom — Momentary
MOS — Metal-oxide semiconductor
MOSFET — Metal-oxide semiconductor field-effect transistor
ms — Millisecond
msb — Most significant bit
mV — Millivolt
mW — Milliwatt
Mx — Maxwell (Weber)
My — Myria (10^4)
N — Newton; North
n — Nano (10^{-9})
N-m — Newton meter
N-s/m^2 — Newton second per square meter
N/m^2 — Newton per square meter (pascal)
nA — Nanoampere
Nand — Not AND
nc — No coil; no connection; normally closed
nelec — Nonelectric

Table 6-3. Letter Symbols and Abbreviations (Cont.)

neut — Neutral
nF — Nanofarad
nf — Noise figure; noise frequency
nm — Nanometer
nmag — Nonmagnetic
NMOS — N-channel metal-oxide semiconductor
no — Normally open
nol — Normal overload
nom — Nominal
NOR — Not OR
norm — Normal
ns — nanosecond
nyl — Nylon
oc — Over current
oco — Open-close-open
ocr — Over-current relay
Oe — Oersted (ampere per meter)
ohm — Ohmmeter
op — amp-Operational amplifier
opr — Operate
orly — Overload relay
osc — Oscillate; oscillator
osmv — One-shot multivibrator
out — Output
ovld — Overload
ovrd — Override
P — Pico (10^{-12});Peta (10^{15}); poise (pascal second)
p — Pole; probe
Pa — Pascal
pa — Pulse amplifier
pam — Pulse-amplitude modulation
pc — Printed circuit; program counter
pcm — Pulse code modulation; pulse count modulation
pct — Percent
pdm — Pulse-duration modulation
pec — Photoelectric cell
pelec — Photoelectric
pent — Pentode
permb — Permeability
pF — Picofarad
pf — Power factor; pulse frequency
pfm — Pulse-frequency modulation
ph — Phase
phen — Phenolic

Table 6-3. Letter Symbols and Abbreviations (Cont.)

phm — Phase meter
pim — Pulse-interval modulation
piv — Peak inverse voltage
pk — Peak
pls — Pulse
plyph — Polyphase
PMOS — P-channel metal-oxide semiconductor
pnp — Positive-negative-positive
pos — Positive
pot — Potentiometer
pr — Pair
preamp — Preamplifier
pri — Primary
prv — Peak reverse voltage
pt — Pint
pu — Pickup
pvc — Polyvinyl chloride
pW — Picowatt
pwr sply — Power supply
pwr — Power
Q — Quality factor; quantity of electricity
qt — Quart
qtz — Quartz
R — Resistance; resistor; roentgen
r — Radius
r/min — Revolutions per minute
r/s — Revolutions per second
rad — Radian
rad — Radio
RAM — Random-access memory
RC cpld — Resistance-capacitance coupled
RC — Resistance-capacitance, radio control
rcdr — Recorder
RCTL — Resistor-capacitor-transistor logic
rcv — Receive
rcvr — Receiver
rd — Rad (gray)
rechrg — Recharge
rect — Rectifier
ref — Reference
reg — Regenerate
res — Resistor
resn — Resonant
rev cur — Reverse current

Table 6-3. Letter Symbols and Abbreviations (Cont.)

rf — Radio frequency
rfc — Radio-frequency choke
rfi — Radio-frequency interference
rgltr — Regulator
rh — Right hand
rifi — Radio interference field intensity
rinsul — Rubber insulation
RL — Resistance-inductance
RLC — Resistance-inductance-capacitance
rly — Relay
rms — Root mean square
rmt — Remote
ROM — Read-only memory
rot — Rotate
rpm — Revolutions per minute
rps — Revolutions per second
rpt — Repeat
RTL — Resistor-transistor logic
rtr — Rotor
rtty — Radio teletypewriter
S — Siemens (Ω^{-1})
S — Signal power; voltage standing-wave ratio
s — second (time)
sb — Sideband
sc — Single contact
scc — Single-conductor cable; single cotton-covered
sce — Single cotton enamel
schem — Schematic
scr — Short-circuit ratio; silicon-controlled rectifier
scrterm — Screw terminal
sec — Secondary
sel — Selector
semicond — Semiconductor
sens — Sensitive; sensitivity
seq — Sequence
servo — Servomechanism
sft — Shaft
SH — Shield (electronic device)
sh — Shunt
shf — Superhigh frequency
shld — Shield
short — Short circuit
shtc — Short time constant
sig gen — Signal generator

Table 6-3. Letter Symbols and Abbreviations (Cont.)

sig — Signal
slp — Slope
slv — Sleeve
slwl — Straight-line wavelength
snr — Signal-to-noise ratio
snsr — Sensor
sol — Solenoid
sp sw — Single-pole switch
sp — Single pole
spdt sw — Single-pole, double-throw switch
spdt — Single-pole, double-throw
sq — Square
sqcq — Squirrel cage
sqw — Square wave
sr — Slip ring; split ring
sr — Steradian
SRAM — Static random-access memory
ss — Subsystem
ssb — Single sideband
ssbo — Single swing block oscillator
ssc — Single silk-covered
ssw — Synchro switch
st & sp — Start and stop
st — Sawtooth; Schmitt trigger; single throw
stalo — Stabilized local oscillator
stamo — Stabilized master oscillator
stbscp — Stroboscope
stby — Standby
stdf — Standoff
subassy — Subassembly
submin — Subminiature
substr — Substrate
suppr — Suppressor
svmtr — Servomotor
svo — Servo
sw — Short wave; switch
swbd — Switchboard
swg — Stubs Wire Gauge
swgr — Switchgear
swp exp — Sweep expand
swp gen — Sweep generator
swp integ — Sweep integrator
swp — Sweep
swr — Standing-wave ratio (voltage)

Table 6-3. Letter Symbols and Abbreviations (Cont.)

sym — Symbol
syn — Synchronous
sync — Synchronize
synscp — Synchroscope
sys — System
T — Tera (10^{12}); tesla
t sw — Temperature switch; test switch
t — Temperature; time
tach — Tachometer
tb — Terminal board
tc — Thermocouple; time constant
tcu — Tape control unit
tel — Telephone
telecom — Telecommunications
temp — Temperature
templ — Template
term — Terminal
tet — Tetrode
tf — Thin film
tft — Thin-film transistor
thermo — Thermostat
thms — Thermistor
thrm — Thermal
thymo — Thyratron motor
thyr — Thyristor
tig — Telegraph
tlm — Telemeter
tlmy — Telemetry
tm — Temperature meter
tmx — Telemeter transmitter
tpho — Telephotograph
tpr — Teleprinter
trf — Tuned radio frequency
TS — Telegraph System
tsteq — Test equipment
tt — Teletypewriter
TTL — Transistor-transistor logic
tty — Teletypewriter
tv — Television
tvm — Tachometer voltmeter
u — Unified atomic mass unit
uf — Ultrasonic frequency
uhf — Ultrahigh frequency
UJT — Unijunction transistor

Table 6-3. Letter Symbols and Abbreviations (Cont.)

undc — Undercurrent
undf — Underfrequency
unf — Unfused
unrgltd — Unregulated
usb — Upper sideband
USG — United States Gauge
util — Utility
V — Volt
V/m — Volt per meter
v — Vertical, voltage
VA — Volt ampere
vac — Vacuum
vam — Voltammeter
var — Var
var — Variable; varistor
varistor — Variable resistor
varohm — Var-hour meter
vc — Voice coil
vco — Voltage-controlled oscillator
vd — Voltage drop
vdet — Voltage detector
vdt — Video display terminal
vern — Vernier
vf — Variable frequency, voice frequency
vfo — Variable-frequency oscillator
vfreq clk — Variable-frequency clock
vhf — Very high frequency
vib — Vibrate; vibration
vid — Video; visual
vidamp — Video amplifier
vidf — Video frequency
vlf — Very low frequency
vm — Voltmeter
vo — Voice
vol — Volume
vom — Volt-ohm milliameter
VOX — Voice-operated transmitter keyer
vr — Voltage regulator
vrly — Voltage relay
vsm — Vestigial-sideband modulation
vswr — Voltage standing-wave ratio
vt — Vacuum tube
vtvm — Vacuum-tube voltmeter
VU — Volume unit

Table 6-3. Letter Symbols and Abbreviations (Cont.)

W — Watt
W/(m-K) — Watt per meter Kelvin
W/sr — Watt per steradian square meter
w — Wide
Wb — Weber (V — s)
wb — Wide band
wd — Watt demand meter
wdg — Winding
wfr — Wafer
wg — Waveguide; wire gauge
Wh — Watt-hour
whdm — Watt-hour demand meter
whm — Watt-hour meter
wl — Wavelength
wm — Wattmeter
wnd — Wound
wpg — Wiping
wpm — Words per minute
wr — Wall receptacle
wrg — Wiring
wtrprf — Waterproof
wv — Working voltage
ww — Wire-wound
X — Reactance
X_c — Capacitive reactance
X_l — Inductive reactance
y — Admittance
yd^2 — Square yard
yd^3 — Cubic yard
yd — Yard
yr — Year
Z — Impedance; zone
za — Zero adjusted

Semiconductor Abbreviations

Table 6-4 shows abbreviations for semiconductor devices.

Table 6-4. Semiconductor Abbreviations

α	Alpha (ratio of collector to emitter current)
A, a	Anode
β	Beta (current gain)
B, b	Base
C, c	Collector, cathode
C_{IN}	Input capacitance
C_{OUT}	Output capacitance
C_{PD}	Power dissipation capacity
C_X	Expander output capacitance
D, d	Drain
E, e	Emitter
F_{alpha}	Alpha cut-off frequency
F_{CLOCK}	Input clock frequency
F_O	Output frequency
F_T	Current gain bandwidth product
F_{max}	Maximum operating frequency or clock
G, g	Gate
G_c	Current gain
G_{PB}	Common base power gain
G_{PE}	Common emitter power gain
G_{fs}	Common-source forward transfer conductance
G_v	Voltage gain
I_C	Maximum collector current
I_{CC}	Supply current
I_D	Drain current
I_{DD}	Quiescent device current
$I_{f(av)}$	Maximum average forward current
I_{fm}	Maximum peak forward current

Table 6-4. Semiconductor Abbreviations (Cont.)

I_{fs}	Maximum peak surge current
I_{FSM}	Maximum peak surge current
I_I	Input current at maximum input voltage
I_{IH}	High-level input current
I_{IL}	Low-level input current
I_{IN}	Input current
I_O	Average rectified current, forward
I_{OH}	High-level output current
I_{OL}	Low-level output current
I_{OS}	Short-circuit output current
I_R	Average rectified current, reverse
I_r	Maximum dc reverse current
I_X	Expander current
K, k	Cathode
NF	Noise figure
P_D	Maximum device power dissipation
P_T	Total power input, all terminals
P_{in}	Input power
P_{out}	Output power
PIV	Peak inverse voltage
Q	True output
R_O	Output impedance
S, s	Source
T	Temperature
T_A	Operating free-air temperature
T_L	Lead temperature
T_{PHL}	Propagation delay time, high to low level output
T_{PHZ}	Output disable from high level
T_{PLH}	Propagation delay time, low to high level output
T_{PLZ}	Output disable from low level
T_S	Storage temperature range
T_{SU}	Data setup time
T_W	Pulse width
U, u	Bulk (substrate)
V_f	Maximum dc voltage drop
$V_{f(av)}$	Maximum average forward voltage drop
V_{BE}	Base-emitter voltage
V_{CBO}	Maximum collector-base voltage
V_{cc}	Collector supply voltage
V_{CE}	Collector-emitter voltage
V_{CEO}	Maximum collector-emitter voltage
V_{DD}	Dc supply voltage
V_{DS}	Drain-source voltage
V_{EBO}	Maximum emitter-base voltage
V_F	Average forward voltage
V_{GS}	Gate-source voltage
V_{IH}	High-level input voltage
V_{IK}	Input clamp voltage
V_{IL}	Low-level input voltage
V_{IN}	Input voltage
V_{OH}	High-level output voltage
V_{OL}	Low-level output voltage
V_{T+}	Positive-going threshold voltage
V_{T-}	Negative-going threshold voltage

Schematic Symbols for Electronics

Figure 6-1 shows common schematic symbols used for both discrete and larger-scale electronic devices.

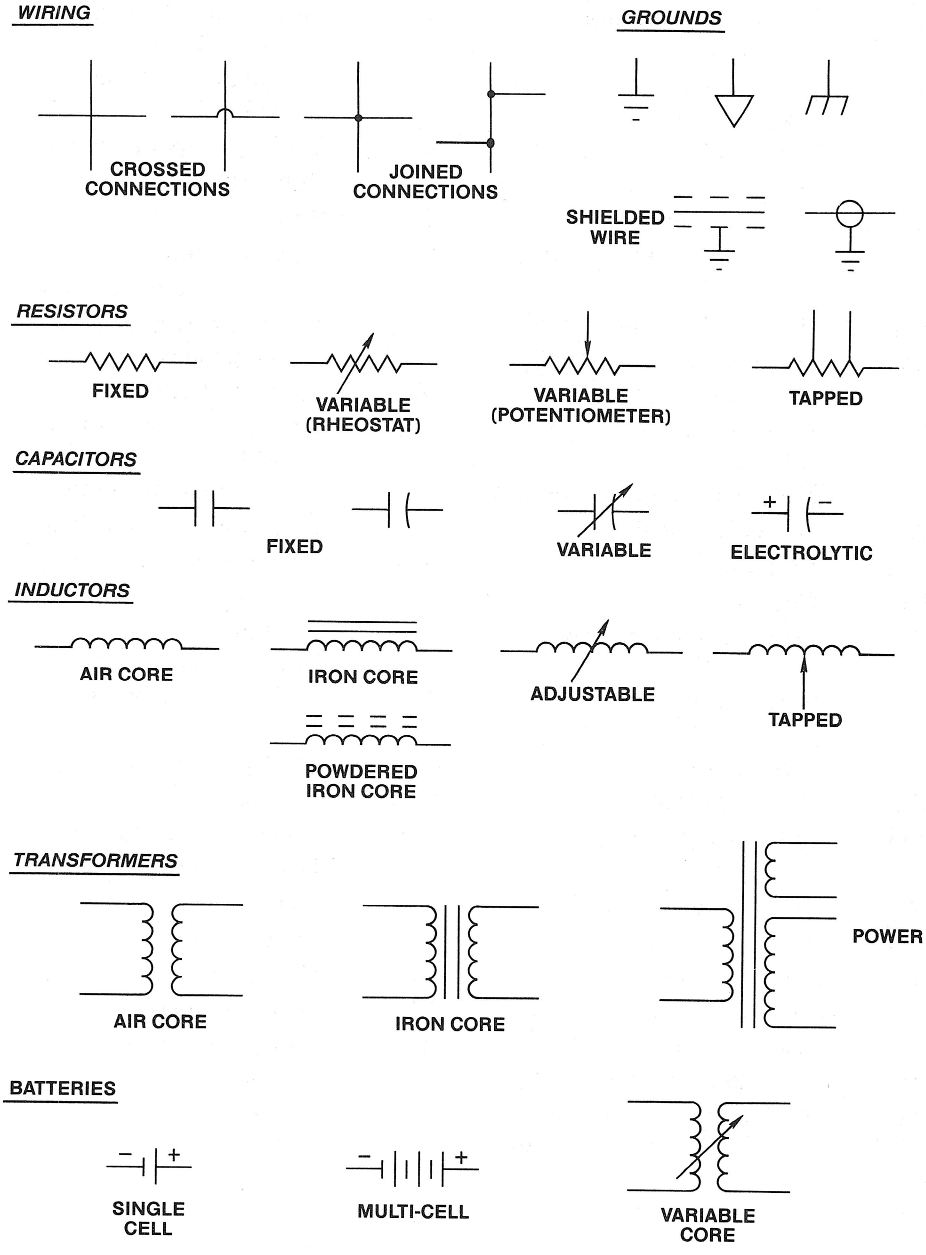


Figure 6-1. Schematic Symbols for Electronics

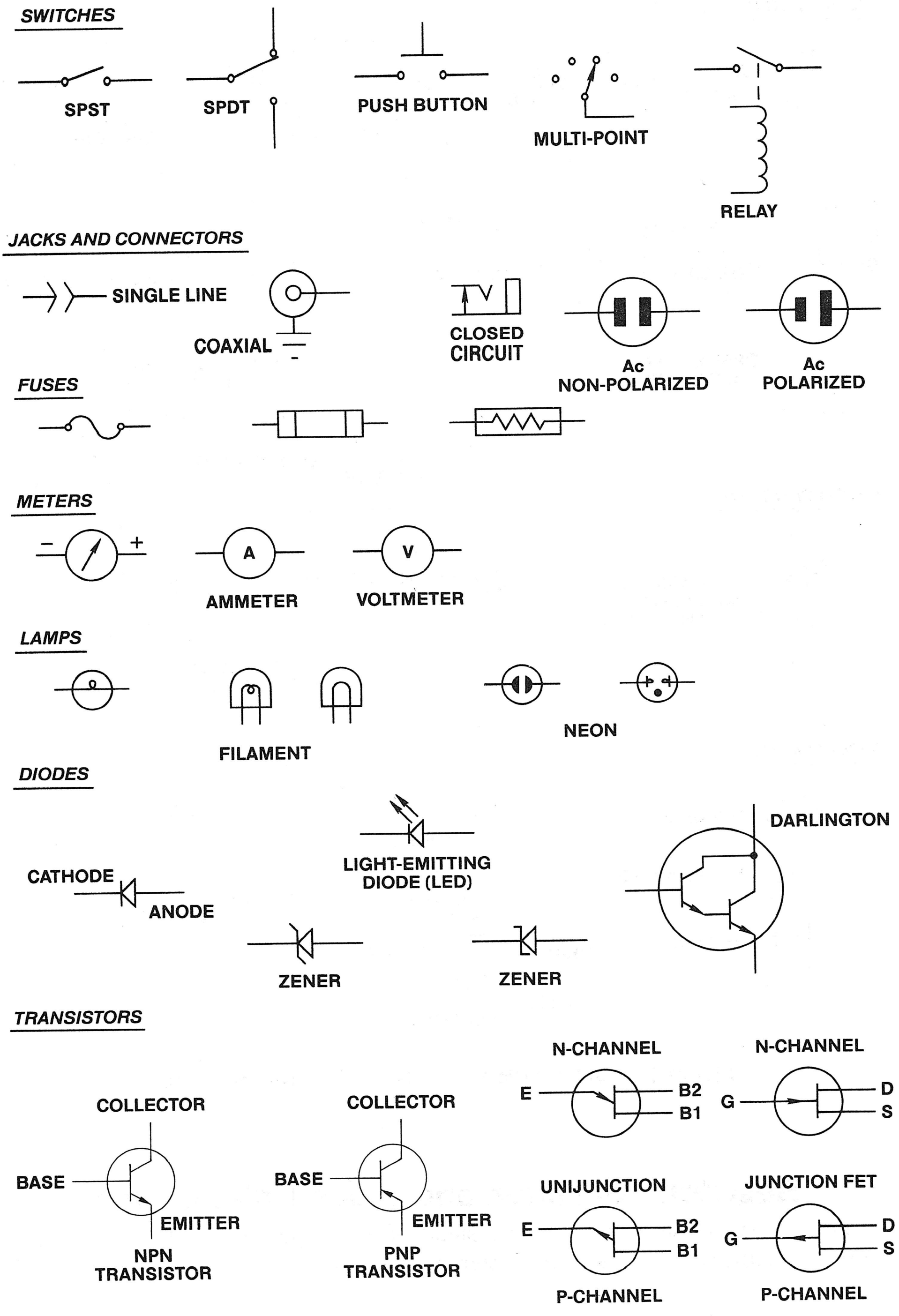


Figure 6-1. Schematic Symbols for Electronics (cont.)

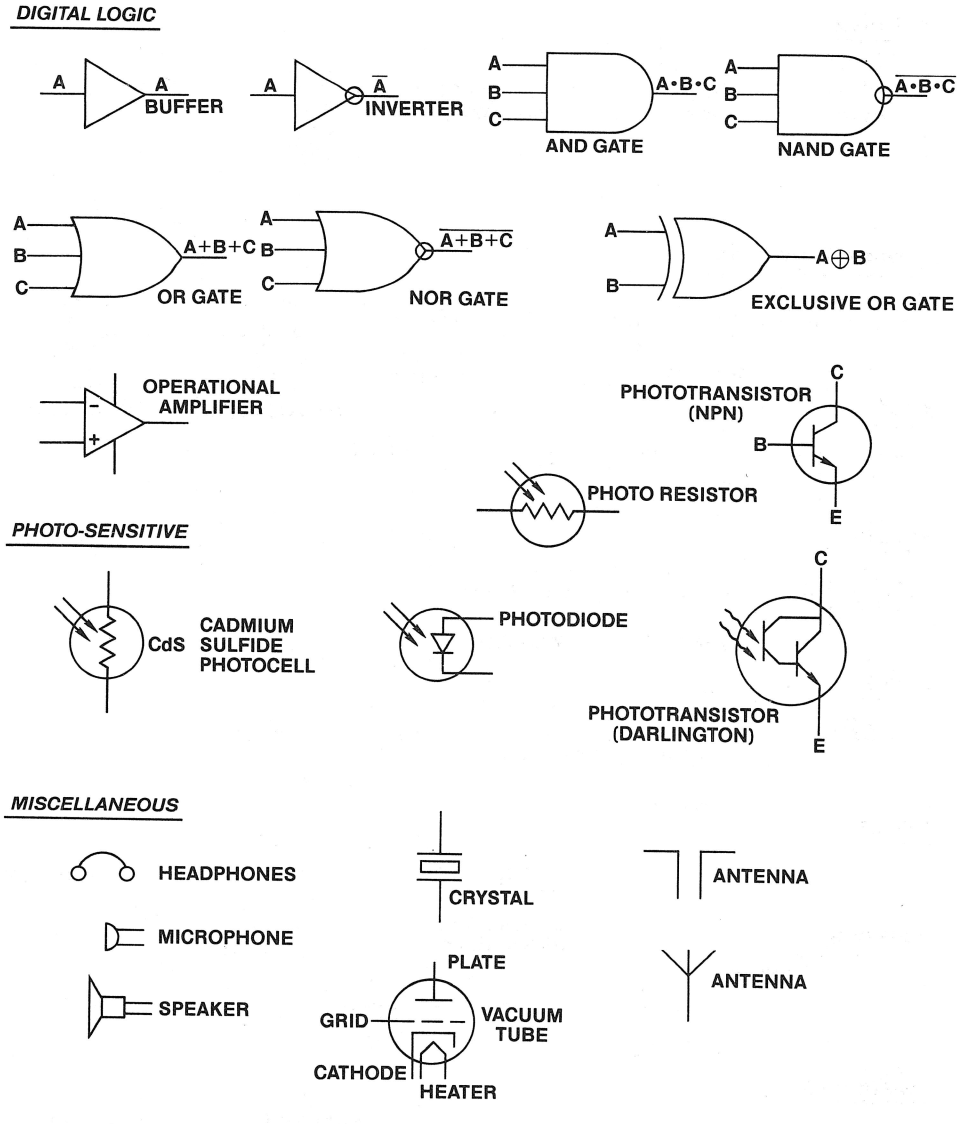


Figure 6-1. Schematic Symbols for Electronics (cont.)

Resistor, Capacitor, and Diode Color Codes

Many resistors use a color code instead of a stamped value. The color code represents either a digit, multiplier, tolerance, or failure rate, as shown in Table 6-5.

Table 6-5. Resistor Color Codes

Color	Digit	Multiplier	Tolerance	Failure Rate
black	0	1		
brown	1	10	± 1%	1.0
red	2	100	± 2%	0.1
orange	3	1000	± 3%	0.01
yellow	4	10000	± 4%	0.001
green	5	100000		
blue	6	1000000		
violet	7	10000000		
gray	8	100000000		
white	9			
gold		0.1	± 5%	
silver		0.01	± 10%	
no color			± 20%	

Most precision resistors have their values stamped on the resistor body. Other resistors are color coded with three or four colored bands, offset towards one end of the resistor. The first two bands of these resistors are digits, the next the multiplier, and the next, if present, the tolerance. A resistor coded red, red, orange, silver, for example, would be 2, 2, x 1000, 10% tolerance, or 22,000 ohms, 10% tolerance. Some film-type resistors have three significant figures and use five colored bands. The failure rate is not generally found on common resistors. Figure 6-2 shows colored band coding and other types of resistor coding.

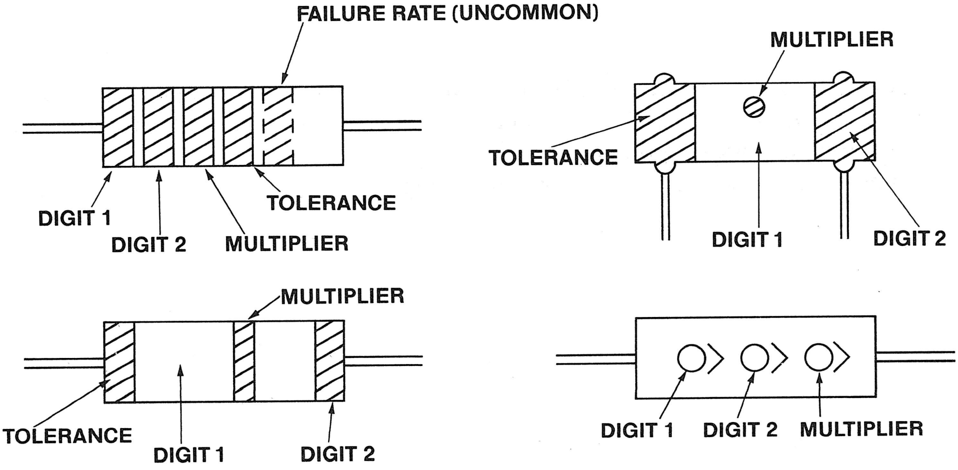


Figure 6-2. Resistor Color Coding

Capacitors are usually not color coded. When they are, however, they use the same digit codes as resistors. The multiplier code is also the same with the exception of ceramic capacitors, which use gray for a multiplier of 0.01 and white for a multiplier of 0.1. The value is in picofarads. Capacitor codes are shown in Table 6-6 below.

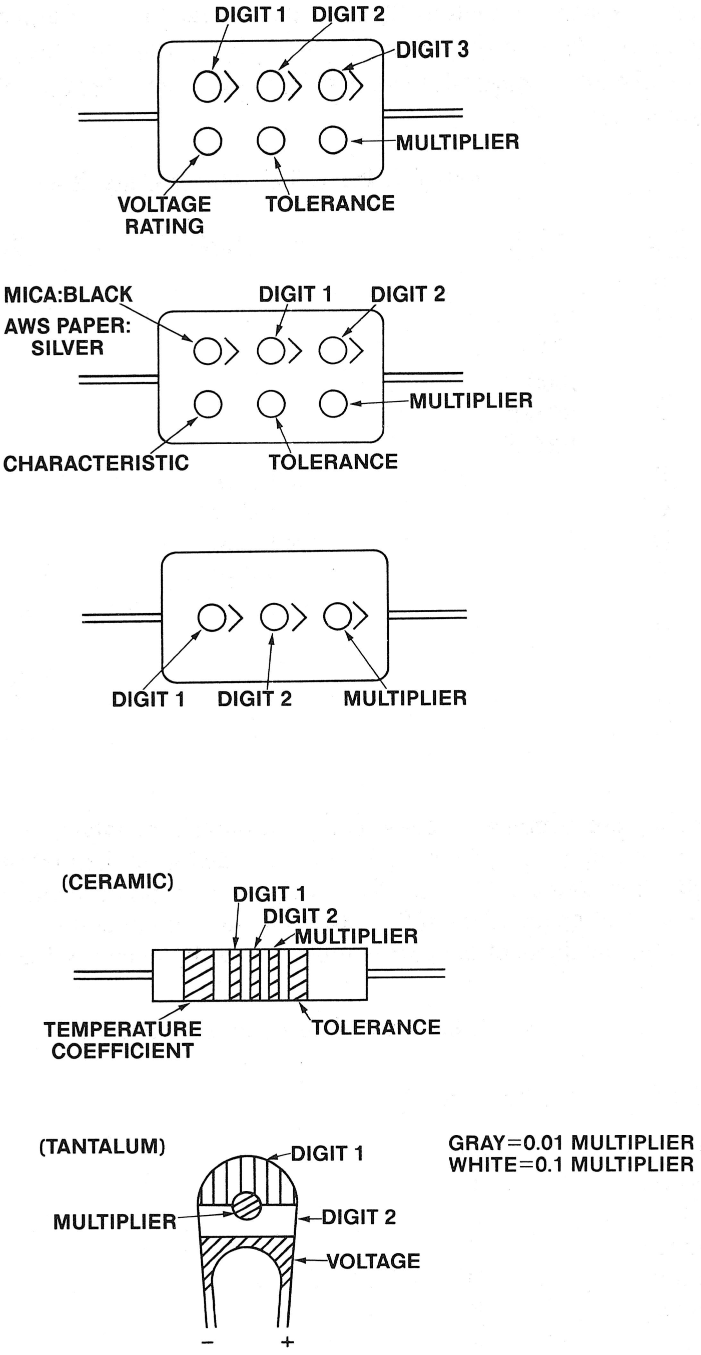
Table 6-6. Capacitor Color Codes

Color	Digit	Tolerance
black	0	1
brown	1	10
red	2	100
orange	3	1000
yellow	4	10000
green	5	100000
blue	6	
violet	7	
gray	8	0.01 (cer)
white	9	0.1 (cer)
gold		0.1 (others)
silver		0.01 (others)
no color		

(cer) = ceramic only
(others) = all except ceramic

Color coding for capacitor tolerance varies with the type of capacitor. In addition, there may be color coding for temperature coefficient, operating temperature range, and dc working voltage.

Typical coding schemes are shown in Figure 6-3.



GRAY=0.01 MULTIPLIER
WHITE=0.1 MULTIPLIER

Figure 6-3. Capacitor Color Coding

Some capacitors, such as film and disk capacitors, use a printed code of four characters. The first three characters are digits while the last is a letter. The first three indicate the capacitor value while the last indicates the tolerance. Coding is shown in Table 6-7.

Table 6-7. Printed Codes for Capacitors

Digit	Multiplier	<= 10pF	>10pF
0	1		
1	10		
2	100		
3	1000		
4	10000		
5	100000		
B		± 0.1 pF	
C		± 0.25 pF	
D		± 0.5 pF	
F		± 1.0 pF	± 1%
G		± 2.0 pF	± 2%
H			± 3%
J			± 5%
K			± 10%
M			± 20%

Diodes are sometimes color coded, although in many cases the identifying number is stamped on the part. The color code for diodes identifies the diode part number, for example a 1NXXXX part. The color bands indicate the last three digits of the part number and the suffix letter. The same color coding as in the table above is used for the digits of the part number. The suffix letter coding follows Table 6-8.

Table 6-8. Diode Suffix Letter Coding

Color	Suffix Letter
black	none
brown	A
red	B
orange	C
yellow	D
green	E
blue	F
violet	G
gray	H
white	J

Figure 6-4 shows the diode color scheme.

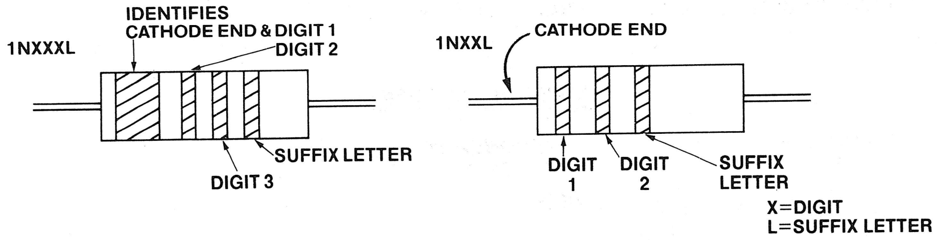


Figure 6-4. Diode Color Coding

DIP Device Pin Numbering

Many plastic and ceramic semiconductor devices are made in a configuration known as a dual inline package, or DIP. Standard pin numbering for the most common size DIP devices is shown in Figure 6-5. Pin 1 on DIP devices is usually denoted by a small dot or other coding.

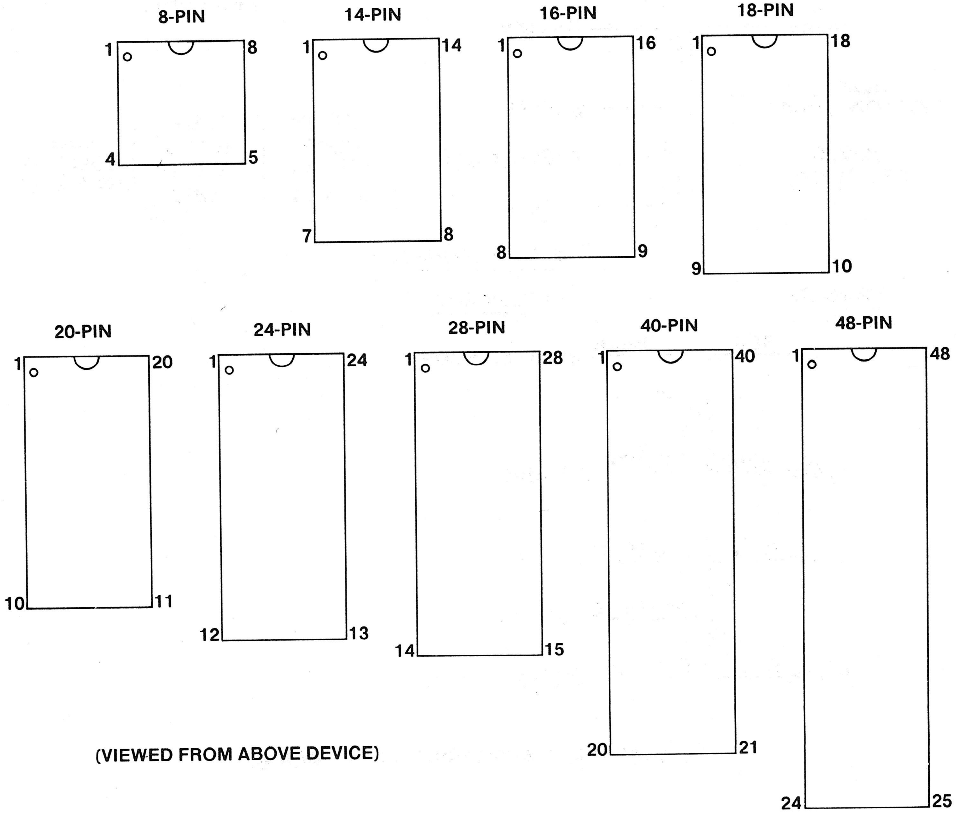


Figure 6-5. DIP Device Pin Numbering

Transformer Color Coding

Figure 6-6 shows color coding for common types of transformers. Plate and filament references refer to vacuum tube use.

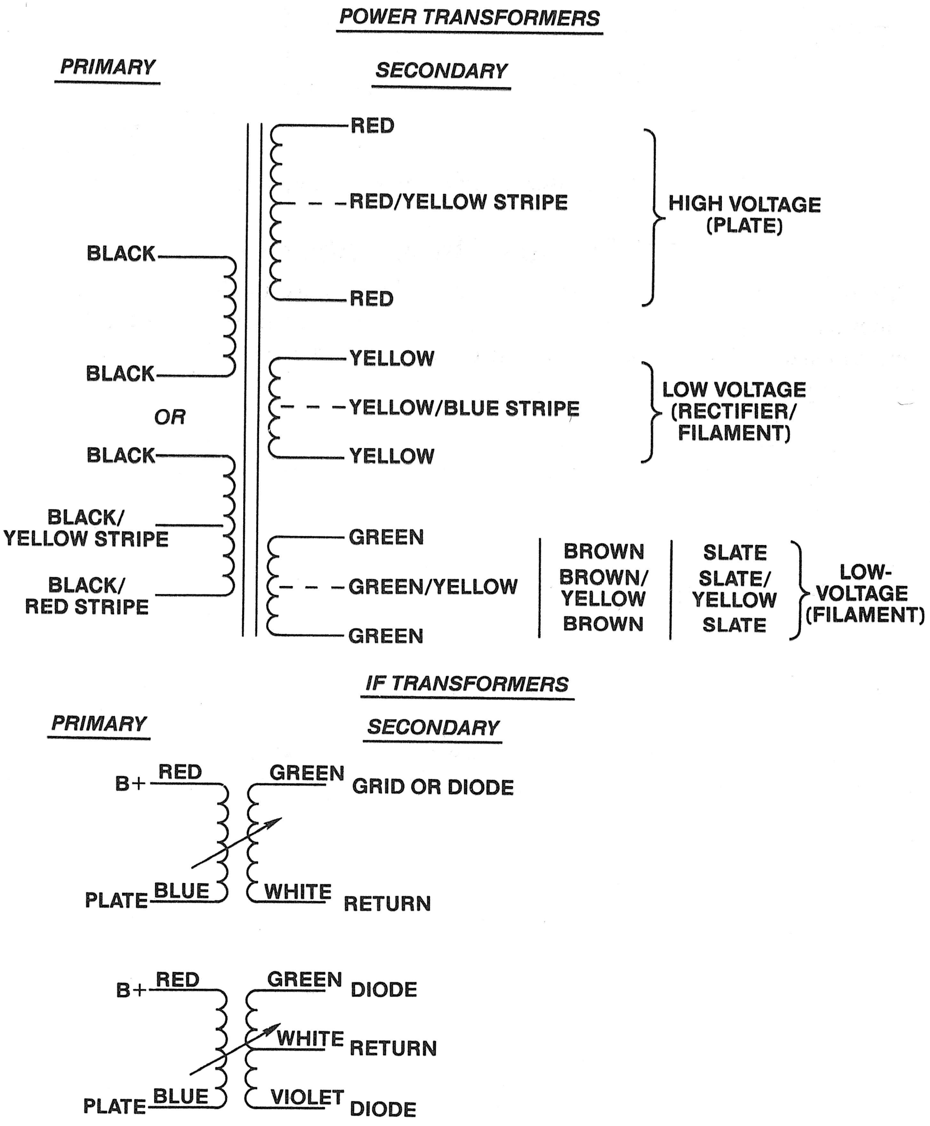


Figure 6-6. Transformer Color Coding

AUDIO OUTPUT AND INTERSTAGE TRANSFORMERS

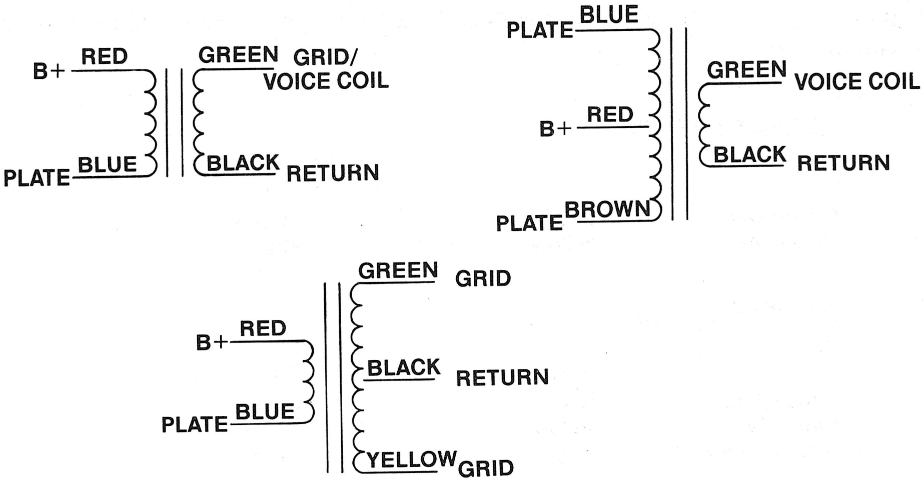
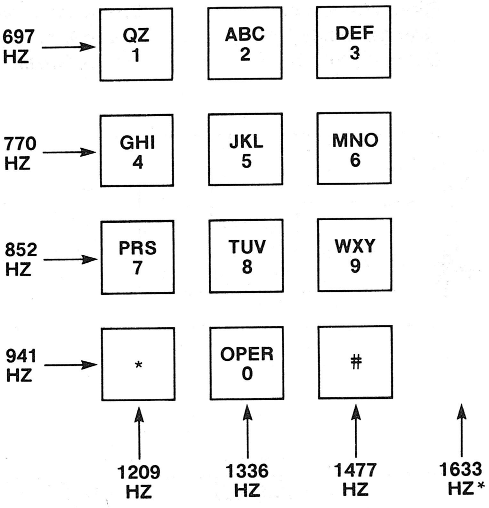


Figure 6-6. Transformer Color Coding (Cont.)

Touch Tone Dialing Frequencies

The standard frequencies produced by a Touchtone dialing telephone or by electronic devices emulating the Touchtone dialing system are shown in Figure 6-7. Each key produces a low group frequency and a simultaneous high group frequency dependent upon its "row-column" position.



*NOT USED ON COMMON TELEPHONES

Figure 6-7. Touchtone Dialing Frequencies

Telephone Connections and Color Coding

Typical color coding for four- and six-conductor telephone cables is shown in Figure 6-8. Also shown are common ways of attaching multiple telephones to one telephone line.

Four-Conductor Cables

	Ring	Tip
Circuit One:	Red	Green
Circuit Two:	Yellow	Black

Six-Conductor Cables

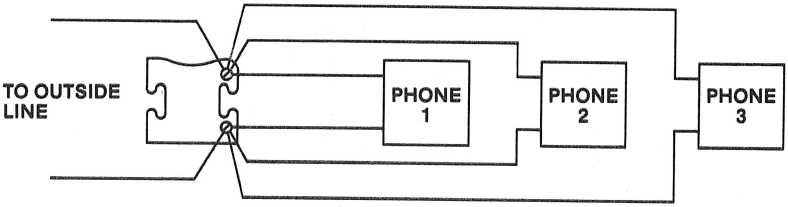
	Ring	Tip
Circuit One:	Red	Green
Circuit Two:	Yellow	Black
Circuit Three:	Blue	White

Circuit One:	Red	Green
Circuit Two:	Yellow	Black
Circuit Three:	Blue/White band	White/Blue band

Circuit One:	Blue	White/Blue band
Circuit Two:	Orange	White/Orange band
Circuit Three:	Green	White/Green band

Circuit One:	Blue/White band	White/Blue band
Circuit Two:	Orange/White band	White/Orange band
Circuit Three:	Green/White band	White/Green band

INDIVIDUAL CABLES



LOOPING

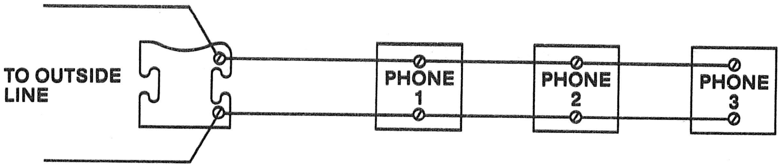


Figure 6-8. Telephone Connections and Color Coding

Greek Alphabet

The Greek alphabet is shown in Table 6-9. The first character represents the upper case character and the second the lower case character.

Table 6-9. Greek Alphabet

Α	α	alpha
Β	β	beta
Γ	γ	gamma
Δ	δ	delta
Ε	ϵ	epsilon
Ζ	ζ	zeta
Η	η	eta
Θ	θ	theta
Ι	ι	iota
Κ	κ	kappa
Λ	λ	lambda
Μ	μ	mu
Ν	ν	nu
Ξ	ξ	xi
Ο	ο	omicron
Π	π	pi
Ρ	ρ	rho
Σ	σ	sigma
Τ	τ	tau
Υ	υ	upsilon
Φ	ϕ	phi
Χ	χ	chi
Ψ	ψ	psi
Ω	ω	omega

Greek Symbols Used for Electronics

Table 6-10 shows common uses of Greek symbols for electrical quantities.

Table 6-10. Greek Symbols in Electronics

α	angles, coefficients, attenuation constant, transistor current transfer ratio, cutoff frequency
β	angles, coefficients, phase constant, transistor current amplification factor
γ	angles, electrical conductivity, propagation constant
Γ	complex propagation constant
Δ	increment or decrement, determinant, permittivity

Table 6-10. Greek Symbols in Electronics (Cont.)

ϵ	dielectric constant, permittivity, electric intensity, base of natural logarithms
ζ	coordinates, coefficients
η	intrinsic impedance, efficiency, surface charge density hysteresis
θ	angular phase displacement, time constant, reluctance, angles
ι	unit vector
κ	susceptibility, coeeficient of coupling, Boltzmann's constant
λ	wavelength, attenuation constant
Λ	permeance, total inductance
μ	permeability, amplification factor, "micro"
ν	reluctivity, frequency
ξ	coordinates
π	3.14159..
ρ	resistivity, volume charge density, coordinates, reflection coefficient
σ	surface charge density, complex propagation constant, electrical conductivity, leakage coefficient, deviation
Σ	summation
τ	time constant, volume resistivity, time-phase displacement, transmission factor, density
ϕ	magnetic flux, angles, phase deviation
Φ	scalar potential
χ	electric susceptibility, angles, modulation index
ψ	dielectric flux, phase difference, coordinates, angles
ω	angular velocity
Ω	ohms, solid angle

Copper Wire Table

Table 6-11 shows the electrical characteristics of a range of sizes of bare copper wire. Area is shown in circular mils, an area equal to the area of a circle with a diameter of one mil (one thousandth of an inch). Maximum current is calculated by using the constant 700 circular mils per ampere.

Table 6-11. Copper Wire Table

AWG	Diameter (In.)	Area (Mils)	Length (Ft./Lb.)	Ohms Per 1000 Ft.	Max Current (Amps)
0000	.4601	211750	1.561	.04900	302.6
000	.4097	167921	1.968	.06179	240.0
00	.3648	133163	2.482	.07791	190.3
0	.3249	105600	3.130	.09825	150.9
1	.2893	83742	3.947	.1239	119.7
2	.2576	66409	4.977	.1562	94.9

Figure 6-11. Copper Wire Table (Cont.)

AWG	Diameter (In.)	Area (Mils)	Length (Ft./Lb.)	Ohms Per 1000 Ft.	Max Current (Amps)
3	.2294	52663	6.276	.1970	75.3
4	.2043	41762	7.915	.2484	59.7
5	.1819	33118	9.980	.3133	47.3
6	.1620	26263	12.59	.3951	37.5
7	.1443	20827	15.87	.4982	29.8
8	.1285	16516	20.01	.6282	23.6
9	.1144	13097	25.24	.7922	18.7
10	.1019	10386	31.82	.9989	14.8
11	.0907	8237	40.1	1.26	11.8
12	.0808	6532	50.6	1.59	9.33
13	.0720	5180	63.8	2.00	7.40
14	.0641	4108	80.5	2.53	5.87
15	.0571	3257	101	3.19	4.65
16	.0508	2583	128	4.02	3.69
17	.0453	2048	161	5.06	2.93
18	.0403	1624	203	6.39	2.32
19	.0359	1288	257	8.05	1.84
20	.0320	1022	324	10.2	1.46
21	.0285	810	408	12.8	1.16
22	.0253	642	514	16.1	.918
23	.0226	509	649	20.4	.728
24	.0201	404	818	25.7	.577
25	.0179	320	1032	32.4	.458
26	.0159	254	1301	40.8	.363
27	.0142	201	1641	51.5	.288
28	.0126	160	2069	64.9	.228
29	.0113	127	2609	81.9	.181
30	.0100	100	3290	103.3	.144
31	.00892	79.7	4148	130	.114
32	.00795	63.2	5231	164	.090
33	.00708	50.1	6596	207	.072
34	.00630	39.7	8318	261	.057
35	.00561	31.5	10489	329	.045
36	.00500	25.0	13227	415	.036
37	.00445	19.8	16679	524	.028
38	.00396	15.7	21033	660	.022
39	.00353	12.5	26523	833	.018
40	.00314	9.88	33446	1050	.014
41	.00280	7.84	42176	1324	.011
42	.00249	6.21	53184	1669	.0089
43	.00222	4.93	67066	2105	.0070

Figure 6-11. Copper Wire Table (Cont.)

AWG	Diameter (In.)	Area (Mils)	Length (Ft./Lb.)	Ohms Per 1000 Ft.	Max Current (Amps)
44	.00198	3.91	84571	2655	.0056
45	.00176	3.10	106645	3348	.0044
46	.00157	2.46	134481	4221	.0035

Electrical Characteristics of Logic Families

Bipolar Logic Families (listed in chronological order of development):

DCTL	Direct-coupled Transistor Logic. First commercial integrated circuits. Poor noise immunity. High current. Not used for new designs. Low cost.
RTL	Resistor-Transistor Logic. Low speed, poor noise immunity. Low fan-out capability. Not used for new designs.
DTL	Diode-Transistor Logic. Low speed. Not used for new designs.
HTL	High-Threshold Logic. Greater noise immunity than DTL.
RCTL	Resistor-Capacitor-Transistor Logic. Similar to RTL, but higher speed.
TTL	(Also T^2L.) Transistor-transistor Logic. The most popular logic family at present. Greater speed and noise immunity than RTL or DTL. High fan out capability. Moderate power consumption. Identified by 54XXX or 74XXX series numbers. Sub-family types include high-speed (54/74HXXX); low-power (54/74LXXX); Low-power Schottky (54/74LSXXX); Schottky (54/74SXXX).
ECL	Emitter-Coupled Logic. Very high-speed, high input impedance, low output impedance. Popular for new designs of high-speed circuitry.
I^2L	Integrated Injection logic. Increased density and decreased power consumption over TTL.

Metal-Oxide Semiconductor Logic Families (listed in chronological order of development):

PMOS	P-Channel MOS. Lower power consumption than bipolar logic. Lower speed than bipolar logic. Oldest MOS type. Least popular for new designs.
NMOS	N-Channel MOS. Twice the speed of PMOS. Increased density over PMOS. Greatly increased density over bipolar families. Popular for new designs, especially microprocessors.
CMOS	Complementary MOS. High noise immunity. Very low power consumption. Great fan out capability. Popular for new designs where low power consumption is required, including microprocessor designs.

Section 7.
Computer Data

Binary, Octal, Decimal, and Hexadecimal Values.

Table 7-1 lists decimal numbers from 0 through 255 and their equivalent values in binary, octal, and hexadecimal.

Table 7-1. Binary, Octal, Decimal, and Hexadecimal Values

Binary	Oct	Dec	Hex
00000000	000	0	00
00000001	001	1	01
00000010	002	2	02
00000011	003	3	03
00000100	004	4	04
00000101	005	5	05
00000110	006	6	06
00000111	007	7	07
00001000	010	8	08
00001001	011	9	09
00001010	012	10	0A
00001011	013	11	0B
00001100	014	12	0C
00001101	015	13	0D
00001110	016	14	0E
00001111	017	15	0F
00010000	020	16	10
00010001	021	17	11
00010010	022	18	12
00010011	023	19	13
00010100	024	20	14
00010101	025	21	15
00010110	026	22	16
00010111	027	23	17
00011000	030	24	18
00011001	031	25	19
00011010	032	26	1A
00011011	033	27	1B
00011100	034	28	1C
00011101	035	29	1D
00011110	036	30	1E
00011111	037	31	1F
00100000	040	32	20
00100001	041	33	21
00100010	042	34	22
00100011	043	35	23

Table 7-1. Binary, Octal, Decimal, and Hexadecimal Values (Cont.)

Binary	Oct	Dec	Hex
00100100	044	36	24
00100101	045	37	25
00100110	046	38	26
00100111	047	39	27
00101000	050	40	28
00101001	051	41	29
00101010	052	42	2A
00101011	053	43	2B
00101100	054	44	2C
00101101	055	45	2D
00101110	056	46	2E
00101111	057	47	2F
00110000	060	48	30
00110001	061	49	31
00110010	062	50	32
00110011	063	51	33
00110100	064	52	34
00110101	065	53	35
00110110	066	54	36
00110111	067	55	37
00111000	070	56	38
00111001	071	57	39
00111010	072	58	3A
00111011	073	59	3B
00111100	074	60	3C
00111101	075	61	3D
00111110	076	62	3E
00111111	077	63	3F
01000000	100	64	40
01000001	101	65	41
01000010	102	66	42
01000011	103	67	43
01000100	104	68	44
01000101	105	69	45
01000110	106	70	46
01000111	107	71	47
01001000	110	72	48
01001001	111	73	49
01001010	112	74	4A
01001011	113	75	4B
01001100	114	76	4C
01001101	115	77	4D
01001110	116	78	4E

Table 7-1. Binary, Octal, Decimal, and Hexadecimal Values (Cont.)

Binary	Oct	Dec	Hex
01001111	117	79	4F
01010000	120	80	50
01010001	121	81	51
01010010	122	82	52
01010011	123	83	53
01010100	124	84	54
01010101	125	85	55
01010110	126	86	56
01010111	127	87	57
01011000	130	88	58
01011001	131	89	59
01011010	132	90	5A
01011011	133	91	5B
01011100	134	92	5C
01011101	135	93	5D
01011110	136	94	5E
01011111	137	95	5F
01100000	140	96	60
01100001	141	97	61
01100010	142	98	62
01100011	143	99	63
01100100	144	100	64
01100101	145	101	65
01100110	146	102	66
01100111	147	103	67
01101000	150	104	68
01101001	151	105	69
01101010	152	106	6A
01101011	153	107	6B
01101100	154	108	6C
01101101	155	109	6D
01101110	156	110	6E
01101111	157	111	6F
01110000	160	112	70
01110001	161	113	71
01110010	162	114	72
01110011	163	115	73
01110100	164	116	74
01110101	165	117	75
01110110	166	118	76
01110111	167	119	77
01111000	170	120	78
01111001	171	121	79

Table 7-1. Binary, Octal, Decimal, and Hexadecimal Values (Cont.)

Binary	Oct	Dec	Hex
01111010	172	122	7A
01111011	173	123	7B
01111100	174	124	7C
01111101	175	125	7D
01111110	176	126	7E
01111111	177	127	7F
10000000	200	128	80
10000001	201	129	81
10000010	202	130	82
10000011	203	131	83
10000100	204	132	84
10000101	205	133	85
10000110	206	134	86
10000111	207	135	87
10001000	210	136	88
10001001	211	137	89
10001010	212	138	8A
10001011	213	139	8B
10001100	214	140	8C
10001101	215	141	8D
10001110	216	142	8E
10001111	217	143	8F
10010000	220	144	90
10010001	221	145	91
10010010	222	146	92
10010011	223	147	93
10010100	224	148	94
10010101	225	149	95
10010110	226	150	96
10010111	227	151	97
10011000	230	152	98
10011001	231	153	99
10011010	232	154	9A
10011011	233	155	9B
10011100	234	156	9C
10011101	235	157	9D
10011110	236	158	9E
10011111	237	159	9F
10100000	240	160	A0
10100001	241	161	A1
10100010	242	162	A2
10100011	243	163	A3
10100100	244	164	A4

Table 7-1. Binary, Octal, Decimal, and Hexadecimal Values (Cont.)

Binary	Oct	Dec	Hex
10100101	245	165	A5
10100110	246	166	A6
10100111	247	167	A7
10101000	250	168	A8
10101001	251	169	A9
10101010	252	170	AA
10101011	253	171	AB
10101100	254	172	AC
10101101	255	173	AD
10101110	256	174	AE
10101111	257	175	AF
10110000	260	176	B0
10110001	261	177	B1
10110010	262	178	B2
10110011	263	179	B3
10110100	264	180	B4
10110101	265	181	B5
10110110	266	182	B6
10110111	267	183	B7
10111000	270	184	B8
10111001	271	185	B9
10111010	272	186	BA
10111011	273	187	BB
10111100	274	188	BC
10111101	275	189	BD
10111110	276	190	BE
10111111	277	191	BF
11000000	300	192	C0
11000001	301	193	C1
11000010	302	194	C2
11000011	303	195	C3
11000100	304	196	C4
11000101	305	197	C5
11000110	306	198	C6
11000111	307	199	C7
11001000	310	200	C8
11001001	311	201	C9
11001010	312	202	CA
11001011	313	203	CB
11001100	314	204	CC
11001101	315	205	CD
11001110	316	206	CE
11001111	317	207	CF

Table 7-1. Binary, Octal, Decimal, and Hexadecimal Values (Cont.)

Binary	Oct	Dec	Hex
11010000	320	208	D0
11010001	321	209	D1
11010010	322	210	D2
11010011	323	211	D3
11010100	324	212	D4
11010101	325	213	D5
11010110	326	214	D6
11010111	327	215	D7
11011000	330	216	D8
11011001	331	217	D9
11011010	332	218	DA
11011011	333	219	DB
11011100	334	220	DC
11011101	335	221	DD
11011110	336	222	DE
11011111	337	223	DF
11100000	340	224	E0
11100001	341	225	E1
11100010	342	226	E2
11100011	343	227	E3
11100100	344	228	E4
11100101	345	229	E5
11100110	346	230	E6
11100111	347	231	E7
11101000	350	232	E8
11101001	351	233	E9
11101010	352	234	EA
11101011	353	235	EB
11101100	354	236	EC
11101101	355	237	ED
11101110	356	238	EE
11101111	357	239	EF
11110000	360	240	F0
11110001	361	241	F1
11110010	362	242	F2
11110011	363	243	F3
11110100	364	244	F4
11110101	365	245	F5
11110110	366	246	F6
11110111	367	247	F7
11111000	370	248	F8
11111001	371	249	F9
11111010	372	250	FA

Table 7-1. Binary, Octal, Decimal, and Hexadecimal Values (Cont.)

Binary	Oct	Dec	Hex
11111011	373	251	FB
11111100	374	252	FC
11111101	375	253	FD
11111110	376	254	FE
11111111	377	255	FF

RS-232-C Signals and Pinout.

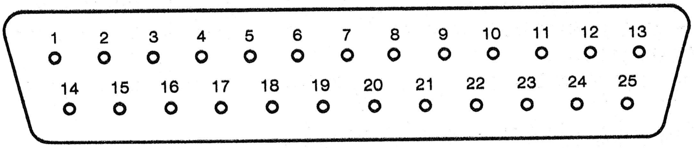
The EIA RS-232-C standard defines communication between data terminal equipment and data communications equipment. The standard defines both the physical connections and electrical aspects. Figure 7-1 shows the pinout and signals of a standard RS-232-C 25-pin male connector. The female connector is a mirror image.

Figure 7-1. RS-232-C Pins and Signals

Pin	Signal	Abbreviation
1	Protective ground*	
2	Transmitted data*	TX
3	Received data*	RX
4	Request to send*	RTS
5	Clear to send*	CTS
6	Data set ready*	DSR
7	Signal ground*	GND
8	Carrier detect (received line signal detector)*	CD
9	Reserved for data set testing	
10	Reserved for data set testing	
11	Unassigned	
12	Secondary received line signal detector	
13	Secondary clear to send	
14	Secondary transmitted data	
15	Transmission signal element timing (DCE source)	
16	Secondary received data	
17	Receiver signal element timing (clock; DCE source)	
18	Unassigned	
19	Secondary request to send	
20	Data terminal ready*	DTR
21	Signal quality detector	
22	Ring indicator*	RI
23	Data signal rate selector (speed select)	
24	Transmit signal element timing (clock; DTE source)	
25	Unassigned	

* = commonly used signals

RS-232-C Connector (looking in to male)

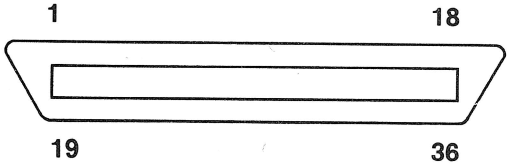


Centronics Signals and Pinout.

The electrical and physical connections for parallel printers used by Centronics, a printer manufacturer, have become a de facto standard for computer equipment. Most microcomputers and many larger computers use the "Centronics bus" interface to parallel printers. It is shown in Figure 7-2.

Figure 7-2. Centronics (Parallel Printer) Connections

Pin	I/O	Signal
1	O	Data strobe*
2	O	Data bit 1
3	O	Data bit 2
4	O	Data bit 3
5	O	Data bit 4
6	O	Data bit 5
7	O	Data bit 6
8	O	Data bit 7
9	O	Data bit 8
10	I	Acknowledge*
11	I	Busy
12	I	Paper out or print off
13	I	Selected
14	—	Ground
15	—	— —
16	—	Ground
17	—	Chassis ground
18	—	+5 volts
19-30	—	Twisted pair ground
31	O	Input prime*
32	I	Printer fault*
33	—	Ground
34	—	— —
35	—	— —
36	—	— —



CONNECTOR ON PRINTER SHOWN, LOOKING IN

Notes:

1. Signals with asterisk (*) suffix indicate that signal is negative true.
2. I/O indicates direction of signal in terms of computer (I is computer input, printer output).
3. Not all signals are used on every printer; minimum signals are pins 1-11 and 17.
4. Connector type is Amphenol 57-40360.

Baudot Code.

Early data communications equipment used a five-level code called Baudot code (in the U.S.). This code is still widely in use today (with language variations). Five levels, or bits allow 32 code combinations. Shifting to either a "Letters" or "Figures" group by one of the codes expands upon the basic 32 codes. The most common United States Baudot code is shown in Table 7-2.

Table 7-2. Baudot Codes

Code	Letters Case	Figures Case
00000	----------blank---------	
00001	E	3
00010	--------line feed-------	
00011	A	—
00100	----------space---------	
00101	S	BELL
00110	I	8
00111	U	7
01000	--carriage return--	
01001	D	$
01010	R	4
01011	J	’
01100	N	,
01101	F	!
01110	C	:
01111	K	(
10000	T	5
10001	Z	"
10010	L	)
10011	W	2
10100	H	# or motor stop
10101	Y	6
10110	P	0
10111	Q	1
11000	O	9
11001	B	?
11010	G	&
11011	---shift to figures---	
11100	M	.
11101	X	/
11110	V	;
11111	---shift to letters---	

ASCII Codes

ASCII (American Standard Code for Information Interchange) codes are used by microcomputer and peripheral equipment manufacturers to define text and control characters. See Table 7-3. The ASCII code is supported by ANSI, the American National Standards Institute. The ASCII eighth (most significant bit) is frequently used on computers to provide an additional 128 codes—values of 128 through 255—for additional computer functions.

ASCII codes from 0 through 31 are called control codes and provide for communication control, formatting, and information separation.

Table 7-3. ASCII Codes

	Dec	Hex	ASCII	
"CONTROL" CODES	0	00	NUL	(Null)
	1	01	SOH	(Start of heading)
	2	02	STX	(Start of text)
	3	03	ETX	(End of text)
	4	04	EOT	(End of transmission)
	5	05	ENQ	(Enquiry)
	6	06	ACK	(Acknowledge)
	7	07	BEL	(Bell)
	8	08	BS	(Backspace)
	9	09	HT	(Horizontal tab)
	10	0A	LF	(Line feed)
	11	0B	VT	(Vertical tab)
	12	0C	FF	(Form feed)
	13	0D	CR	(Carriage return)
	14	0E	SO	(Shift out)
	15	0F	SI	(Shift in)
	16	10	DLE	(Data Link Escape)
	17	11	DC1	(Device control 1)
	18	12	DC2	(Device control 2)
	19	13	DC3	(Device control 3)
	20	14	DC4	(Device control 4)
	21	15	NAK	(Negative acknowledge)
	22	16	SYN	(Synchronous idle)
	23	17	ETB	(Block)
	24	18	CAN	(Cancel)
	25	19	EM	(End of medium)
	26	1A	SUB	(Substitute)
	27	1B	ESCAPE	(Escape)
	28	1C	FS	(File separator)
	29	1D	GS	(Group separator)
	30	1E	RS	(Record separator)
	31	1F	US	(Unit separator)
	32	20	SPACE	
	33	21	!	
	34	22	"	

Table 7-3. ASCII Codes (Cont.)

Dec	Hex	ASCII
35	23	#
36	24	$
37	25	%
38	26	&
39	27	'
40	28	(
41	29	)
42	2A	*
43	2B	+
44	2C	,
45	2D	–
46	2E	.
47	2F	/
48	30	0
49	31	1
50	32	2
51	33	3
52	34	4
53	35	5
54	36	6
55	37	7
56	38	8
57	39	9
58	3A	:
59	3B	;
60	3C	<
61	3D	=
62	3E	>
63	3F	?
64	40	@
65	41	A
66	42	B
67	43	C
68	44	D
69	45	E
70	46	F
71	47	G
72	48	H
73	49	I
74	4A	J
75	4B	K
76	4C	L
77	4D	M

Table 7-3. ASCII Codes (Cont.)

Dec	Hex	ASCII
78	4E	N
79	4F	O
80	50	P
81	51	Q
82	52	R
83	53	S
84	54	T
85	55	U
86	56	V
87	57	W
88	58	X
89	59	Y
90	5A	Z
91	5B	[
92	5C	\
93	5D	]
94	5E	^
95	5F	_
96	60	`
97	61	a
98	62	b
99	63	c
100	64	d
101	65	e
102	66	f
103	67	g
104	68	h
105	69	i
106	6A	j
107	6B	k
108	6C	l
109	6D	m
110	6E	n
111	6F	o
112	70	p
113	71	q
114	72	r
115	73	s
116	74	t
117	75	u
118	76	v
119	77	w
120	78	x

Table 7-3. ASCII Codes (Cont.)

Dec	Hex	ASCII
121	79	y
122	7A	z
123	7B	{
124	7C	¦
125	7D	}
126	7E	~
127	7F	DEL (Rubout)

Section 8

Miscellaneous Data

Metric System

Physical characteristics such as length, mass, and electrical current were first expressed in arbitrary units based on body measurements or plant seeds. Two basic systems are in widespread use today, the English system and metric system. Much of the world uses the metric system for common measurements. The United States and Great Britain use the English system for common measurements, but rely on the metric system for precise scientific measurements.

Units for the metric system were standardized in the 1960s by an international conference. The international system of units are called "S.I." units after the French title of the standard. S.I. units use a series of prefixes to express a wide range of great or small quantities. The S.I. unit of frequency, the hertz, for example, may be expressed in such forms as as megahertz or gigahertz; 54 megahertz is more easily grasped than 54,000,000 hertz. The S.I. Unit of electrical capacitance, the farad, allows such forms as 470 picofarad, rather than the more difficult form 0.000000000470 farad.

Comon metric prefixes used in electrical work are shown in Table 8-1, along with the multiplication factor that must be used to convert a quantity expressed in the prefix to the "base" unit.

Example: 100 milliseconds is equal to 100 x 10^{-3} seconds, or .100 seconds.

Table 8-1. Common Metric Prefixes

Prefix	Abbreviation	Multiplication Factor	Pronunciation
exa	E	10^{18}	ex'a
peta	P	10^{15}	pet'a
tera	T	10^{12}	ter'a
giga	G	10^{9}	ji'ga
mega	M	10^{6}	meg'a
kilo	k	10^{3}	kil'o
hecto	h*	10^{2}	hek'to
deka	da*	10	dek'a
deci	d*	10^{-1}	des'i
centi	c*	10^{-2}	sen'ti
milli	m	10^{-3}	mil'i
micro	µ	10^{-6}	mi'kro
nano	n	10^{-9}	nan'o
pico	p	10^{-12}	pe'co
femto	f	10^{-15}	fem'to
atto	a	10^{-18}	at'to

*Not normally used in electrical work

Table 8-2 shows the conversion factors required to convert from one common prefex form to another.

Example: To convert from 23 gigahertz to metahertz, multiply by 1000.

Table 8-2. Conversion Factors for Prefixes

From	To	Multiply By	Divide By
Gigaunits	Megaunits	1000	
	Kilounits	1,000,000	
	Units	1,000,000,000	
Megaunits	Gigaunits		1000
	Kilounits	1000	
	Units	1,000,000	
Kilounits	Gigaunits		1,000,000
	megaunits		1000
	units	1000	
units	gigaunits		1,000,000,000
	megaunits		1,000,000
	kilounits		1000
	milliunits	1000	
	microunits	1,000,000	
	nanounits	1,000,000,000	
	picounits	10^{12}	
Milliunits	units		1000
	microunits	1000	
	nanounits	1,000,000	
	picounits	1,000,000,000	
Microunits	units		1,000,000
	nanounits	1000	
	picounits	1,000,000	
picounits	units		1,000,000,000
	milliunits	1000	
	microunits	1,000,000	
	nanounits	1,000,000,000	

Conversion Factors

Table 8-3 lists common conversion factors for converting one form of measurement of a physical quantity into another. The "Multiply by" column shows the factor to be multiplied times the "From" quantity to get the units listed under the "To" column. The "Converse - Multiply by" column shows the converse—multiply the "To" quantity by the factor to get the "From" quantity units.

Table 8-3. Conversion Factors

From	To	Multiply by	Converse – Multiply by
Acres	Square feet	43,560	2.204 x 10^{-5}
Acres	Square miles	0.0015625	640
Acres	Square yards	4840	2.0661 x 10^{-4}
Ampere-turns	Gilberts	1.256	0.7957
Angstrom	Meters	1 x 10^{-10}	1 x 10^{10}
Atmosphere	Pascals	1.0133 x 10^{5}	9.869 x 10^{-6}
Atmospheres	Feet of water	0.02950	33.89
Atmospheres	Inches of mercury	0.03342	29.94
Atmospheres	Pounds per sq. inch	0.06804	14.70
Bar	Pascals	1 x 10^{5}	1 x 10^{-5}
Barn	Square meters	1 x 10^{-28}	1 x 10^{28}
Barrels	Gallons	31.5	0.0317
Becquerels	Curies	2.70 x 10^{-11}	3.7 x 10^{10}
Becquerels	Rutherfords	1 x 10^{-6}	1 x 10^{6}
BTUs	Foot-pounds	0.001285	833.33
BTUs	Joules	0.0009480	1054.9
BTUs per minute	Watts	17.58	5.689 x 10^{-2}
BTUs per minute	Kilowatts	57.1429	0.01758
Bushels	Pecks	4	1/4
Candelas/sq. mtr	Foot-lamberts	0.2918	34.262
Candelas/sq. mtr	Stilbs	1 x 10^{-4}	1 x 10^{4}
Centimeters	Inches	2.54	0.3937
Centimeters	Meters	0.01	100
Circular mils	Square centimeters	5.067 x 10^{-6}	1.973 x 10^{5}
Circular mils	Square mils	0.7854	1.273
Cords	Cubic feet	0.0078	128
Coulombs/kg.	Roentgens	3.876 x 10^{3}	2.579 x 10^{-4}
Cubic cm.	Cubic meters	1 x 10^{-6}	1 x 10^{6}
Cubic cm.	Liters	0.001	1000
Cubic feet	Cords	128	0.0078
Cubic feet	Cubic inches	1728	5.787 x 10^{-4}
Cubic feet	Cubic meters	35.3147	0.0283
Cubic feet	Cubic yards	1/27	27
Cubic inches	Cubic feet	5.787 x 10^{-4}	1728
Cubic inches	Fluid ounces	0.5543	1.804
Cubic inches	Gallons	0.0043	231
Cubic inches	Milliliters (cc)	6.1023	0.1639
Cubic inches	Quarts (liquid)	0.0173	57.75
Cubic meters	Cubic centimeters	1 x 10^{6}	1 x 10^{-6}
Cubic meters	Cubic feet	0.0283	35.3147
Cubic meters	Cubic millimeters	1 x 10^{9}	1 x 10^{-9}
Cubic meters	Cubic yards	0.7295	1.3708

Table 8-3. Conversion Factors (Cont.)

From	To	Multiply by	Converse — Multiply by
Cubic mm.	Cubic meters	1 x 10^{-9}	1 x 10^{9}
Cubic mm.	Liters	1x10^{-6}	1 x 10^{6}
Cubic yards	Cubic feet	27	1/27
Cubic yards	Cubic meters	1.3708	0.7295
Curie	Becquerel	3.7x10^{10}	2.70 x 10^{-11}
Degrees (angle)	Radians	57.2958	0.0175
Degrees C	Degrees F	5/9 (°F – 32)	9/5(°C) + 32
Degrees C	Degrees Kelvin	C + 273.15	K – 273.15
Degrees F	Degrees C	9/5 (°C) + 32	5/9 (°F – 32)
Degrees Kelvin	Degrees C	K – 273.15	C + 273.15
Drams (apoth)	Grains (apoth)	60	0.167
Drams (apoth)	Ounces (apoth)	1/8	8
Drams (avoir)	Grains	27.343	0.0366
Dyne	Newtons	1 x 10^{-5}	1 x 10^{5}
Dynes	Grams	1.02 x 10^{-3}	980.7
Dynes	Pounds	2.248	4.448 x 10^{5}
Ergs	Foot-pounds	1.356 x 10^{7}	0.7375 x 10^{-7}
Ergs per second	Watts	1x10^{-7}	1x10^{7}
Fathom	Meters	1.8288	0.5468
Feet	Inches	12	1/12
Feet	Meters	3.2808	0.3048
Feet	Miles	5280	0.002
Feet	Nautical miles	1.646 x 10^{-4}	6076.1
Feet	Yards	1/3	3
Feet of water	Atmospheres	33.89	0.02950
Feet/minute	Meters/minute	0.3048	3.281
Fermis	Meters	1 x 10^{-15}	1 x 10^{15}
Fluid ounces	Cubic inches	1.804	0.5543
Fluid ounces	Fluidrams	8	1/8
Fluid ounces	Pints	1/16	16
Fluidrams	Fluid ounces	1/8	8
Foot-candles	Lumens per meter	10.076	0.0929
Foot-lamberts	Candela/sq. meters	34.262	0.2918
Foot-pounds	BTUs	833.33	0.001285
Foot-pounds	Ergs	0.7375 x 10^{-7}	1.356 x 10^{7}
Foot-pounds	Horsepower-hours	1.98 x 10^{6}	0.5051 x 10^{-6}
Foot-pounds	Kilowatt-hours	2.655 x 10^{6}	0.3766 x 10^{-6}
Foot-pounds/min.	Horsepower	3.3 x 10^{4}	0.3030 x 10^{-4}
Foot-pounds/min.	Watts	2.26 x 10^{-2}	44.26
Foot-pounds/sec.	Horsepower	0.5501 x 10^{3}	1.818 x 10^{-3}
Gallons	Barrels	0.0317	31.5
Gallons	Cubic inches	231	0.0043

Table 8-3. Conversion Factors (Cont.)

From	To	Multiply by	Converse – Multiply by
Gallons	Quarts	4	1/4
Gallons	Liters	0.2642	3.7850
Gauss	Lines per sq. inch	6.452	0.155
Gauss	Teslas	1 x 10^{-4}	1 x 10^{4}
Giberts	Ampere-turns	0.7957	1.256
Grains	Drams (avoir)	0.0366	27.343
Grains	Ounces (avoir)	0.0023	437.5
Grains	Pounds	1.4286 x 10^{-4}	7000
Grains (apoth)	Drams (apoth)	0.167	60
Grains (apoth)	Grains (avoir)	1	1
Grains (apoth)	Grains (troy)	1	1
Grains (apoth)	Ounces (apoth)	0.0021	480
Grains (apoth)	Pounds (apoth)	1.736 x 10^{-4}	5760
Grains (avoir)	Grains (apoth)	1	1
Grains (avoir)	Grains (troy)	1	1
Grains (troy)	Grains (apoth)	1	1
Grains (troy)	Grains (avoir)	1	1
Grains (troy)	Ounces (troy)	0.0021	480
Grains (troy)	Pennyweights	1/24	24
Grains (troy)	Pounds (troy)	1.736 x 10^{-4}	5760
Grams	Dynes	980.7	1.02 x 10^{-3}
Grams	Kilograms	0.001	1000
Grams	Ounces	0.2835	3.5274
Horsepower	Foot-pounds/minute	0.3030 x 10^{-4}	3.3 x 10^{4}
Horsepower	Foot-pounds/second	1.818 x 10^{-3}	0.5501 x 10^{3}
Horsepower	Watts	745.7	1.341 x 10^{-2}
Horsepower (met)	Watts	735.5	1.36 x 10^{-3}
Horsepower-hours	Foot-pounds	0.5051 x 10^{-6}	1.98 x 10^{6}
Inches	Centimeters	0.3937	2.54
Inches	Feet	1/12	12
Inches	Yards	1/36	36
Inches of mercury	Atmospheres	29.94	0.03342
Inches of mercury	Pounds per sq. inch	2.036	0.4912
Joules	BTUs	1054.9	0.0009480
Joules/kilogram	Rads	100	0.01
Kg-calories/min.	Watts	69.77	1.433 x 10^{-2}
Kilogram-calories	Kilojoules	4.186	0.2389
Kilograms	Grams	1000	0.001
Kilograms	Metric tons	0.001	1000

Table 8-3. Conversion Factors (Cont.)

From	To	Multiply by	Converse — Multiply by
Kilograms	Pounds	0.4536	2.2046
Kilograms	Slugs	0.06852	14.593
Kilograms/ sq. meter	Pounds/sq. foot	0.2048	4.882
Kilojoules	Kilogram-calories	0.2389	4.186
Kilometers	Miles	1.6093	0.6214
Kilowatt-hours	Foot-pounds	0.3766×10^{-6}	2.655×10^{6}
Kilowatts	BTUs per minute	0.01758	57.1429
Knots	Miles per hour	0.8690	1.1507
Lines per square inch	Gauss	0.155	6.452
Liters	Cubic centimeters	1000	0.001
Liters	Cubic millimeters	1×10^{6}	1×10^{-6}
Liters	Gallons (US liquid)	3.7850	0.2642
Long tons	Pounds	2240	4.464×10^{-4}
Lumens/square meter	Lux	1	1
Lumens per meter	Foot-candles	0.0929	10.076
Lux	Lumens/sq. meter	1	1
Maxwells	Webers	1×10^{-8}	1×10^{8}
Meters	Angstroms	1×10^{10}	1×10^{-10}
Meters	Fathoms	0.5468	1.8288
Meters	Fermis	1×10^{15}	1×10^{-15}
Meters	Centimeters	100	0.01
Meters	Feet	0.3048	3.2808
Meters	Millimeters	1000	0.001
Meters	Yards	0.9144	1.0936
Meters/minute	Feet/minute	3.281	0.3048
Metric tons	Kilograms	1000	0.001
Mhos	Siemens	1	1
Mhos	Ohms	1/ohms	1/mhos
Microns	Mils	25.4	0.0394
Miles	Feet	0.002	5280
Miles	Kilometers	0.6214	1.6093
Miles	Nautical miles	1.1507	0.8690
Miles	Yards	1760	1/1760
Miles per hour	Knots	1.1507	0.8690
Milliliters (cc)	Cubic inches	0.1639	6.1023
Milliliters (cc)	Ounces (fluid)	0.2957	3.3814
Millimeters	Meters	0.001	1000
Mils	Microns	0.0394	25.4
Nautical miles	Feet	6076.1	1.646×10^{-4}

Table 8-3. Conversion Factors (Cont.)

From	To	Multiply by	Converse — Multiply by
Nautical miles	Miles	0.8690	1.1507
Newtons	Dynes	1×10^{5}	1×10^{-5}
Ohms	Mhos	1/mhos	1/ohms
Ounces	Grams	3.5274	0.2835
Ounces	Pounds	1/16	16
Ounces	Quarts (liquid)	1/32	32
Ounces (apoth)	Drams (apoth)	8	1/8
Ounces (apoth)	Grains (apoth)	480	0.0021
Ounces (avoir)	Grains	437.5	0.0023
Ounces (fluid)	Milliliters (cc)	3.3814	0.2957
Ounces (troy)	Grains (troy)	480	0.0021
Ounces (troy)	Pounds (troy)	1/12	12
Pascals	Atmospheres	9.869×10^{-6}	1.0133×10^{5}
Pascals	Bars	1×10^{-5}	1×10^{5}
Pascals	Piezes	0.001	1000
Pascals	Torrs	7.5×10^{-3}	133.3
Pecks	Bushels	1/4	4
Pecks	Quarts	8	1/8
Pennyweights	Grains (troy)	24	1/24
Piezes	Pascals	1000	0.001
Pints	Fluid ounces	16	1/16
Pints	Quarts (dry)	1/2	2
Pints	Quarts (liquid)	1/2	2
Pounds	Dynes	4.448×10^{5}	2.248
Pounds	Grains	7000	1.4286×10^{-4}
Pounds	Kilograms	2.2046	0.4536
Pounds	Long tons	4.464×10^{-4}	2240
Pounds	Ounces	16	1/16
Pounds	Short tons	0.0005	2000
Pounds (apoth)	Grains (apoth)	5760	1.736×10^{-4}
Pounds (troy)	Grains (troy)	5760	1.736×10^{-4}
Pounds (troy)	Ounces (troy)	12	1/12
Pounds per square inch	Atmospheres	14.70	0.06804
Pounds per square inch	Inches of mercury	0.4912	2.036
Pounds/sq. foot	Kilograms/sq. meter	4.882	0.2048
Quarts	Gallons	1/4	4
Quarts	Pecks	1/8	8
Quarts (dry)	Pints	2	1/2
Quarts (liquid)	Cubic inches	57.75	0.0173
Quarts (liquid)	Ounces	32	1/32

Table 8-3. Conversion Factors (Cont.)

From	To	Multiply by	Converse — Multiply by
Quarts (liquid)	Pints	2	1/2
Rads	Joules/kilogram	0.01	100
Radians	Degrees (angle)	0.0175	57.2958
Rayleighs	Seconds/meter	1 x 10^{10}	1 x 10^{-10}
Rods	Yards	2/11	5 1/2
Roentgens	Coulombs/kilogram	2.579 x 10^{-4}	3.876 x 10^{3}
Rutherfords	Becquerels	1 x 10^{6}	1 x 10^{-6}
Seconds/meter	Rayleighs	1 x 10^{-10}	1 x 10^{10}
Short tons	Pounds	2000	0.0005
Siemens	Mhos	1	1
Slugs	Kilograms	14.593	0.06852
Square centimeters	Circular mils	1.973 x 10^{5}	5.067 x 10^{-6}
Square centimeters	Square inches	6.4516	0.1550
Square centimeter	Square meters	0.0001	10000
Square feet	Acres	43560	2.296 x 10^{-5}
Square feet	Square inches	144	1/144
Square feet	Square meters	10.7639	0.0929
Square feet	Square yards	1/9	9
Square inches	Square centimeters	0.1550	6.4516
Square inches	Square feet	1/144	144
Square meters	Barns	1 x 10^{28}	1 x 10^{-28}
Square meters	Square centimeters	10000	0.0001
Square meters	Square feet	0.0929	10.7639
Square meters	Square millimeters	1 x 10^{9}	1 x 10^{-6}
Square meters	Square yards	0.8361	1.1960
Square miles	Acres	640	0.0016
Square millimeters	Square meters	1 x 10^{-6}	1 x 10^{9}
Square mils	Circular mils	1.273	0.7854
Square rods	Square yards	30 1/4	0.0083
Square yards	Acres	2.066 x 10^{-4}	4840
Square yards	Square feet	9	1/9
Square yards	Square meters	1.1960	0.8361
Square yards	Square rods	0.0083	30 1/4
Stilbs	Candelas/sq. meters	1 x 10^{4}	1 x 10^{-4}
Teslas	Gauss	1 x 10^{4}	1 x 10^{-4}
Torrs	Pascals	133.3	7.5 x 10^{-3}
Unit poles	Webers	1.2566 x 10^{-7}	7.957 x 10^{6}
Watts	BTUs per minute	5.689 x 10^{-2}	17.58

Table 8-3. Conversion Factors (Cont.)

From	To	Multiply by	Converse — Multiply by
Watts	Ergs per second	1 x 10^{7}	1 x 10^{-7}
Watts	Foot-pounds/minute	44.26	2.26 x 10^{-2}
Watts	Horsepower	1.341 x 10^{-2}	745.7
Watts	Horsepower (metric)	1.36 x 10^{-3}	735.5
Watts	Kg-calories/minute	1.433 x 10^{-2}	69.77
Webers	Maxwells	1 x 10^{8}	1 x 10^{-8}
Webers	Unit poles	7.957 x 10^{6}	1.2566 x 10^{-7}
Yards	Feet	3	1/3
Yards	Inches	36	1/36
Yards	Meters	1.0936	0.9144
Yards	Miles	1/1760	1760
Yards	Rods	5 1/2	2/11

Machine Screw and Drill Sizes

Table 8-4 shows drill sizes in decimal and clearance drills and tap sizes for common screws used in electronics.

Table 8-4. Drill Sizes

Size	Decimal	Screw Clearance	Tap for:
80	.0135		
79	.0145		
78	.0156		
1/64	.0156		
77	.0180		
76	.0200		
75	.0210		
74	.0224		
73	.0240		
72	.0250		
71	.0260		
70	.0280		
69	.0292		
68	.0310		
1/32	.0313		
67	.0320		
66	.0330		
65	.0350		
64	.0360		
63	.0370		

Table 8-4. Drill Sizes (Cont.)

Size	Decimal	Screw Clearance	Tap for:
62	.0380		
61	.0390		
60	.0400		
59	.0410		
58	.0420		
57	.0430		
56	.0465		
3/64	.0469		
55	.0520		
54	.0550		
53	.0595		
1/16	.0625		
52	.0635		
51	.0670		
50	.0700		2-56
49	.0730		
48	.0760		
5/64	.0781		
47	.0785		3-48
46	.0810		
45	.0820		
44	.0860	2-56	
43	.0890		4-40
42	.0935		
3/32	.0938		
41	.0960		
40	.0980		
39	.0995	3-48	
38	.1015		
37	.1040		
36	.1065		6-32
7/64	.1094		
35	.1100		
34	.1110		
33	.1130	4-40	
32	.1160		
31	.1200		
1/8	.1250		
30	.1285		
29	.1360		8-32
28	.1405	6-32	
9/64	.1406		
27	.1440		

Table 8-4. Drill Sizes (Cont.)

Size	Decimal	Screw Clearance	Tap for:
26	.1470		
25	.1495		10-24
24	.1520		
23	.1540		
5/32	.1563		
22	.1570		
21	.1590		10-32
20	.1610		
19	.1660	8-32	12-20
18	.1695		
11/64	.1709		
17	.1730		
16	.1770		12-24
15	.1800		
14	.1820		
13	.1850		
3/16	.1875		
12	.1890		
11	.1910	10-24,10-32	
10	.1935		
9	.1960		
8	.1990		
7	.2010		
13/64	.2031		
6	.2040		
5	.2055		
4	.2090	12-20	
3	.2130		14-24
7/32	.2188		
2	.2210		
1	.2280	12-24	
A	.2340		
15/64	.2344		
B	.2380		
C	.2420		
D	.2460		
1/4	.2500		
F	.2570		
G	.2610		
17/64	.2656		
H	.2660		
I	.2720		
J	.2770		

Table 8-4. Drill Sizes (Cont.)

Size	Decimal	Screw Clearance	Tap for:
K	.2810		
9/32	.2813		
L	.2900		
M	.2950		
19/64	.2969		
N	.3020		
5/16	.3125		
O	.3160		
P	.3230		
21/64	.3281		
Q	.3320		
R	.3390		
11/32	.3438		
S	.3480		
T	.3580		
U	.3680		
3/8	.3750		
V	.3770		
W	.3860		
25/64	.3906		
X	.3970		
23/64	.3994		
Y	.4040		
13/32	.4063		
Z	.4130		
27/64	.4219		
7/16	.4375		
29/64	.4531		
15/32	.4688		
31/64	.4844		
1/2	.5000		
33/64	.5156		
17/32	.5313		
35/64	.5469		
9/16	.5625		
37/64	.5781		
19/32	.5938		
39/64	.6094		
5/8	.6250		
41/64	.6406		
21/32	.6563		
43/64	.6719		
11/16	.6875		

Table 8-4. Drill Sizes (Cont.)

Size	Decimal	Screw Clearance	Tap for:
45/64	.7031		
23/32	.7188		
47/64	.7344		
3/4	.7500		
49/64	.7656		
25/32	.7813		
51/64	.7969		
13/16	.8125		
53/64	.8281		
27/32	.8438		
55/64	.8594		
7/8	.8750		
57/64	.8906		
29/32	.9063		
59/64	.9219		
15/16	.9375		
61/64	.9531		
31/32	.9688		
63/64	.9844		
1	1.0000		

62-1085

Radio Shack®
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Electrical

$E = AC\ V_{rms}$

$I = AC\ A_{rms}$

$Z = \Omega_{nominal}$

$W = Watts$

$$E = I Z$$

$$Z = E/I$$

$$I = E/Z$$

$$Watts = E I$$

$$\therefore W = E^2/Z$$

$$E = \sqrt{WZ}$$

$$I = \frac{\sqrt{WZ}}{Z} = \sqrt{\frac{W}{Z}} ; W = I^2 Z$$

$$R = \frac{\sqrt{WZ}}{E/Z}$$

$$\Delta dB = 20 \operatorname{Log} \left(\frac{E_1}{E_2} \right)$$

$$\Delta dB = 20 \operatorname{Log} \left(\frac{\sqrt{WZ}}{\sqrt{WZ}} \right) ; \Delta dB = 20 \operatorname{Log} \left(\frac{\sqrt{W_1}}{\sqrt{W_2}} \right)$$ If Z is const

$$= 10 \operatorname{Log} \frac{W_1}{W_2}$$ If Z is const.

For speaker fuses (Fast-blow) Rule of thumb

$$I = \frac{\sqrt{\frac{W}{Z}}}{2}$$

SOUND.

dB SPL@1M = 10 Log(Watts) + SPL @ 1W/1M

ΔdB SPL = 10 Log($\text{Watts}_1/\text{Watts}_2$) with same sensitivity

Decay of SPL w/ distance

dB SPL@1m - 21 LOG(X meters dist.) = dB SPL @ X meters